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Automotive Gas Turbine Economic Analysis

Williams Research Corp, Walled Lake, Mich

Prepared for

Environmental Protection Agency, Ann Arbor, Mich Div of Advanced Automotive Power Systems Development

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ANN ARBOR, MICHIGAN

AUTOMOTIVE GAS TURBINE ECONOMIC ANALYSIS

FINAL REPORT

DECEMBER 1972

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SPRINGFIELD, VA. 22161

Williams Research Corporation

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REPORT NO. WR-ER11

FINAL REPORT

AUTOMOTIVE GAS TURBINE ECONOMIC ANALYSIS

TO

Environmental Protection Agency
Advanced Automotive Power Systems Development Div.
2929 Plymouth Road
Ann Arbor, Michigan 48105

FROM

Williams Research Corporation
2280 W. Maple Road
Walled Lake, Michigan 48088

19 DECEMBER 1972

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FOREWORD

This report, No. WR-ER11, Entitled "Final Report Automotive Gas Turbine Economic Analysis", is submitted to the Environmental Protection Agency, Division of Advanced Automotive Power Systems Development. The report is submitted pursuant to Contract No. 68-01-0405 between that Agency and Williams Research Corporation and is based on all work accomplished under that contract.

R.T. Hall

R.T. Hall
Project Engineer

W.J. Carry
Project Administrator

PREFACE

Through analysis of a detailed drawing of each part in an automotive gas turbine engine, this report concludes that by the time of production at the rate of one million units per year, the labor and material cost of producing turbine engines will be lower than that of producing piston engines. This report does not claim that Williams Research has a turbine engine today that can be manufactured at a lower cost than the piston engine. It does demonstrate, however, that based on appropriate modifications to each detailed part of an existing Williams Research turbine engine as dictated by the requirements of low cost processing methods, a configuration can be developed that is producible at a cost lower than the piston engine.

Based on the increased spending rate by automobile companies, supplier organizations, and the Government on the development of automotive gas turbine engines and processing methods for turbine parts and based on the assumption that this effort will continue to increase in rate, we believe that production of these engines could begin in the 1978-1980 time period. For this to occur, the automobile companies would have to be convinced by 1975 or 1976 that the gas turbine can be manufactured at a lower cost than the piston engine. The automotive turbine production configuration, therefore, would have to be well defined by 1975 or 1976 in order to develop convincing information relative to the direct labor and materials cost as well as the cost of production facilities and equipment. Work on the development of any new manufacturing processes required for low cost turbine parts would have to be at a state of development permitting accurate cost forecasting.

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SECTION I

Summary

Because of the successful development background of the automotive gas turbine engine and because of its inherently clean combustion system, there has been a growing interest in mass producing automotive gas turbines starting in the late 70's or early 80's. Because of its simplicity, its smaller number of parts and fewer machined surfaces, some have predicted that gas turbine engines will be lower in cost in mass production quantities than the piston engine, particularly when consideration is given to the cost of emissions control equipment that must be added to the conventional engine. Quantitative information, however, has not been available concerning the manufacturing cost of automotive gas turbine engines, nor have questions been answered as to the cost of owning and operating turbine powered cars. This economic analysis was conducted to determine values for these unknowns relative to current production piston engines and to define areas requiring additional development efforts.

Using an existing prototype automotive turbine engine as a baseline, the analysis was initiated by upgrading this engine with conceptual design changes to a configuration that represents the 1975 state of the art for automotive turbines. The engine was analyzed in detail for its producibility, utilizing value analysis techniques to further refine the engine for mass production. Manufacturing processes were studied for their applicability to turbine engine components, and a development program is outlined to foster process development for those areas defined as high cost items.

A computer simulation of a turbine powered vehicle was constructed to determine fuel consumption over a predetermined driving schedule, extended for the anticipated life of the engine. A study was also conducted to determine maintenance and repair costs associated with the automotive turbine engine. Turbine engine cost estimates relative to piston engine maintenance were determined and also extended for the life of the engine.

The results of this analysis indicate that the net cost of ownership of gas turbine powered automobiles should be substantially lower than current and future internal combustion, piston engine powered passenger cars.

This report presents the details and results of the various facets of the automotive gas turbine economic analysis.

SECTION II

Williams Research 1975 Preproduction Automotive Gas Turbine Engine

DESCRIPTION OF PROTOTYPE ENGINE

The Williams Research Corporation automotive gas turbine engine selected as the basis for this economic analysis was originally designed as an automobile engine. The engine is a moderate pressure ratio, regenerative free turbine engine developing 80 shaft horsepower and installed in the front of the automobile, driving the rear wheels through a conventional torque converter and three-speed automatic transmission.

The design of this engine is also conventional and is comprised of a single-shaft gas generator, an annular burner, two side-mounted rotary heat exchangers, an axial-flow free power turbine, and a combined accessory and power reduction gearbox. Low cost, low alloy materials are used for the majority of the components. Components that require high nickel content alloys, such as the turbine rotors and nozzles, are precision investment castings. The combustor, which also requires a high temperature capability, is made from multiple Hastelloy X stampings that are furnace brazed together to form the assembly.

Engine Configuration

The external configuration of the engine is shown in Figure 1 and the internal component arrangement is shown in Figure 2.

The compressor air inlet duct and gearbox are combined into a single unit, which is located at the compressor end of the engine. The gas generator shaft, power turbine shaft, and annular burner are located along the horizontal centerline of the engine is the forward part of the main engine housing. The rear portion of the housing contains the exhaust diffuser. Two rotary heat exchangers are used, one on each side of the main engine housing. The engine oil system is entirely self-contained and utilizes a wet sump.

The engine output shaft is driven through a two-stage reduction gear by the power turbine. The power turbine shaft is concentric with the gas generator shaft, and the rear bearings for both shafts are supported through the power turbine nozzle. The

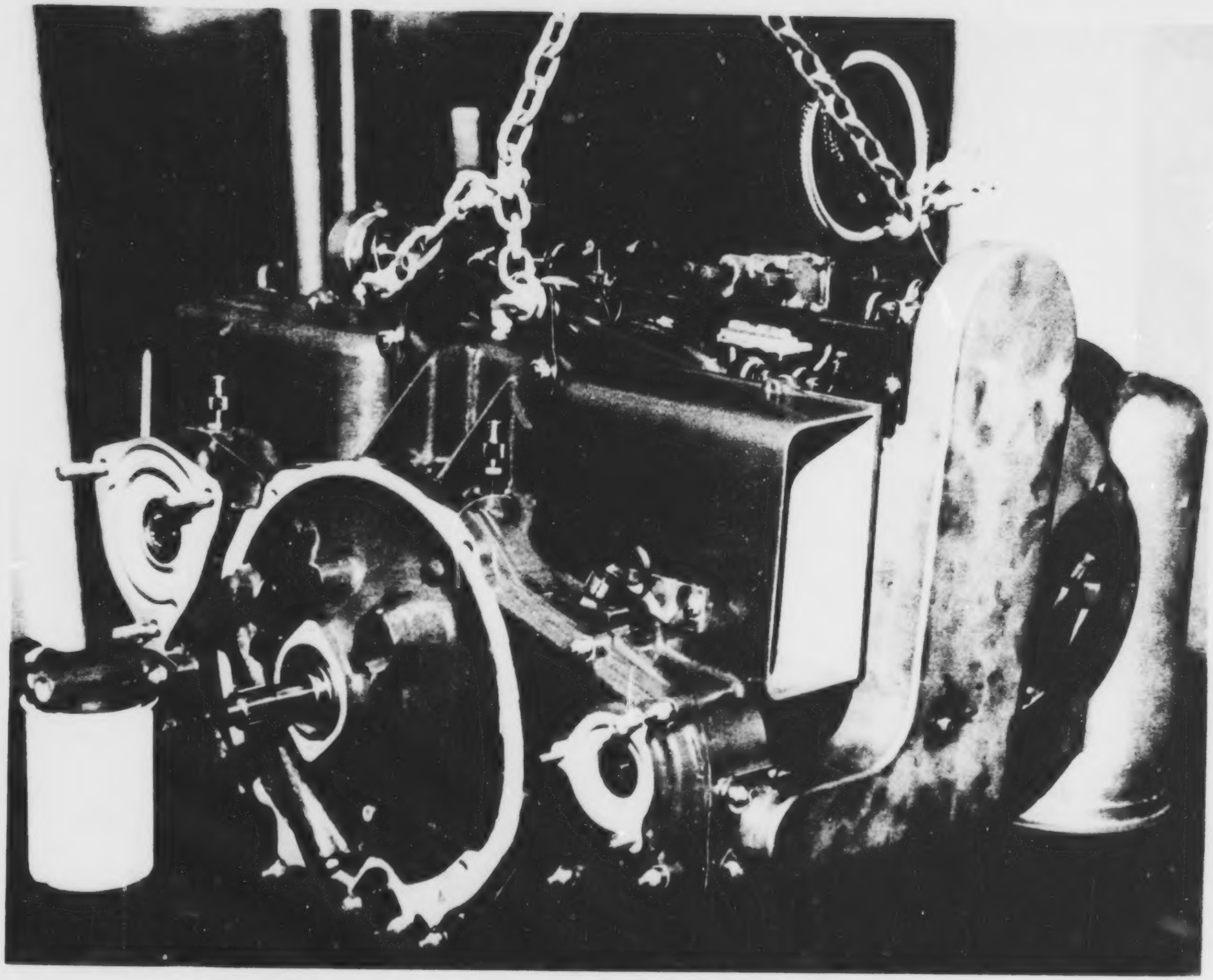

Figure 1. Automotive Gas Turbine Engine - External Configuration

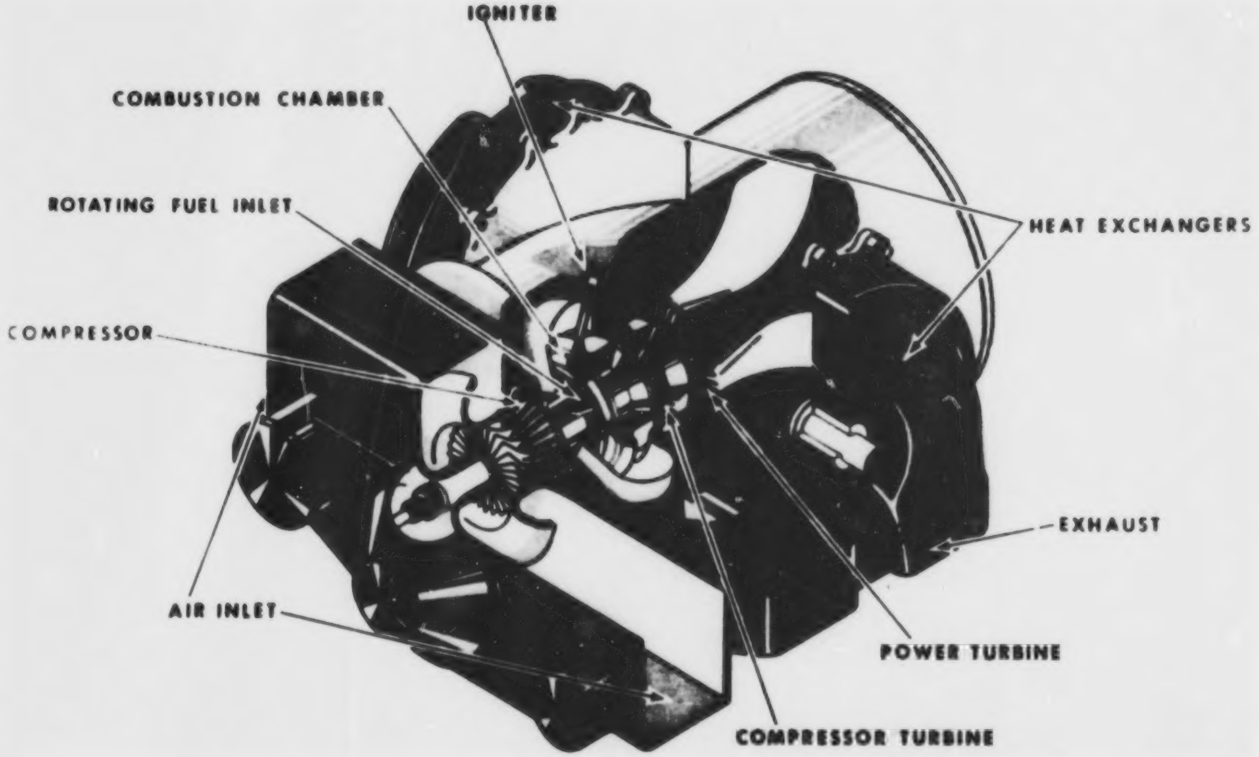
IGNITER
COMBUSTION CHAMBER
ROTATING FUEL INLET
HEAT EXCHANGERS
COMPRESSOR
EXHAUST
AIR INLET
POWER TURBINE
COMPRESSOR TURBINE

Figure 2. Automotive Gas Turbine Engine – Internal Component Arrangement

thrust loads on both shafts are carried by bearings in the gearbox. An overrunning clutch and gear train connect the power turbine and the gas generator rotor.

A bypass valve is used between the gas generator turbine and the power turbine to minimize fuel flow at idle.

Major Engine Components

The major engine components, except for the gearbox, are shown in Figure 3.

Gas Generator Shaft

A single-stage centrifugal compressor and a single-stage axial flow turbine comprise the gas generator shaft. The compressor rotor is a one-piece precision aluminum casting, mechanically coupled to the shaft. The turbine is also a precision casting made from Inconel 713 alloy. The turbine disc is shrunk on the inner shaft and welded.

A spacer tube is located between the turbine disc and the compressor and incorporates the fuel slinger. The inner shaft serves as the draw bolt holding the shaft assembly together.

Burner

The annular burner was chosen because of its compactness and adaptability to the engine-vehicle installation volume limitations. Annular combustors also are characterized by their unusually uniform temperature distribution, high combustion efficiency, and low pressure drop. The annular burner is also believed to possess inherent characteristics that can be utilized to improve emissions, particularly the reduction of NO_X.

Fuel is fed to the burner by a fuel slinger that is attached to gas generator shaft and that rotates at gas generator shaft speed. The fuel is fed to the slinger through three jets located in the stationary fuel distributor.

Power Turbine

The power producing turbine is decoupled from the gas generator shaft during normal operation. Both the nozzle and turbine rotor are precision castings. The power turbine rotor is shrunk on the shaft and retained by a lock-nut and drive pin.

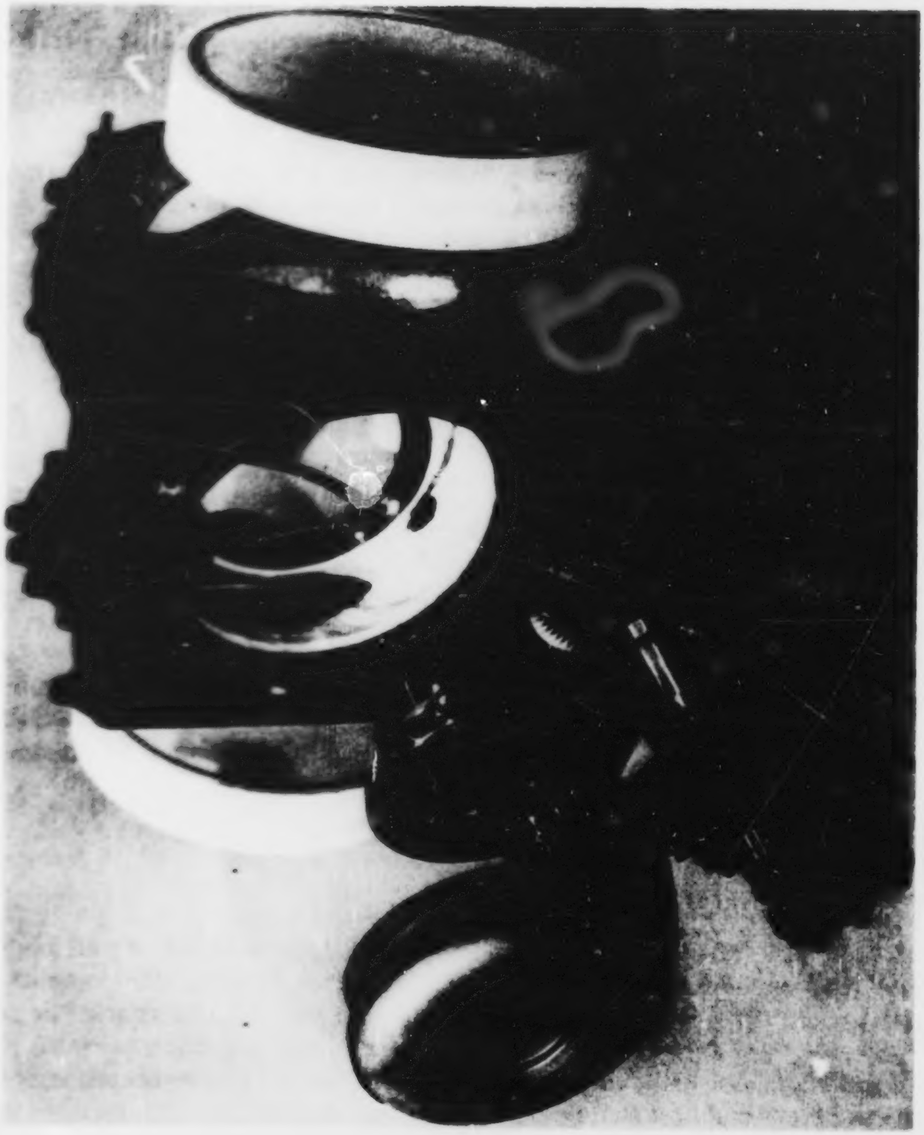

Figure 3. Major Engine Components

Regenerator

A rotary regenerator is an efficient means of reducing the fuel consumption of a turbine engine. It is a device having a high heat storage capability which continuously passes through the exhaust of the engine and then through the path of the compressed air prior to its entering the burner. A large portion of the exhaust heat normally lost to the atmosphere is transferred to the cooler compressed air, resulting in a decrease in the fuel consumption. The rotary regenerator is a compact, reverse flow, heat exchanger.

The engine uses two identical rotary regenerators with stationary rubbing seals. The seals prevent the escape of the high pressure air as it is ducted through the regenerator. The regenerator core material selected is a ceramic and is characterized by its extremely low coefficient of expansion, its ability to resist thermal shock, and its long term stability. The regenerators are contained in separate covers, which are bolted to the main housing.

Main Engine Housing

The main engine housing consists of a single piece of ductile iron casting that forms the main structure. Cast integral with this housing are the transition ducts from the compressor to the regenerator, the regenerator to the burner, and the plenum between the turbine exhaust diffuser and the regenerator housing.

The interior of the main housing is lined with insulation so that all exterior surfaces remain relatively cool (the maximum housing local skin temperature never exceeds 400° F). The casting is designed to minimize the number of minor subassemblies, plumbing, and fittings. The design also minimizes the amount of machining required and lends itself to high volume production techniques.

Gearbox

Figures 4 and 5 show the engine gearbox. In addition to containing all of the reduction gearing and accessory drives, the main gearbox housing also contains the engine air inlet duct. The gearbox provides a reduction from 51,000 rpm at the power turbine to 4,575 rpm at the power output shaft and also a reduction from 61,000 rpm at the gas generator shaft to that speed required by the engine accessories. The overrunning clutch is located between these two shafts.

The gearbox also serves as the sump for the engine lubricant, and a full-flow filter is attached directly to the gearbox. Steel gears are used throughout except for the bronze worm gear in the regenerator drive reduction gearing. Rolling contact bearings are used throughout the gearbox.

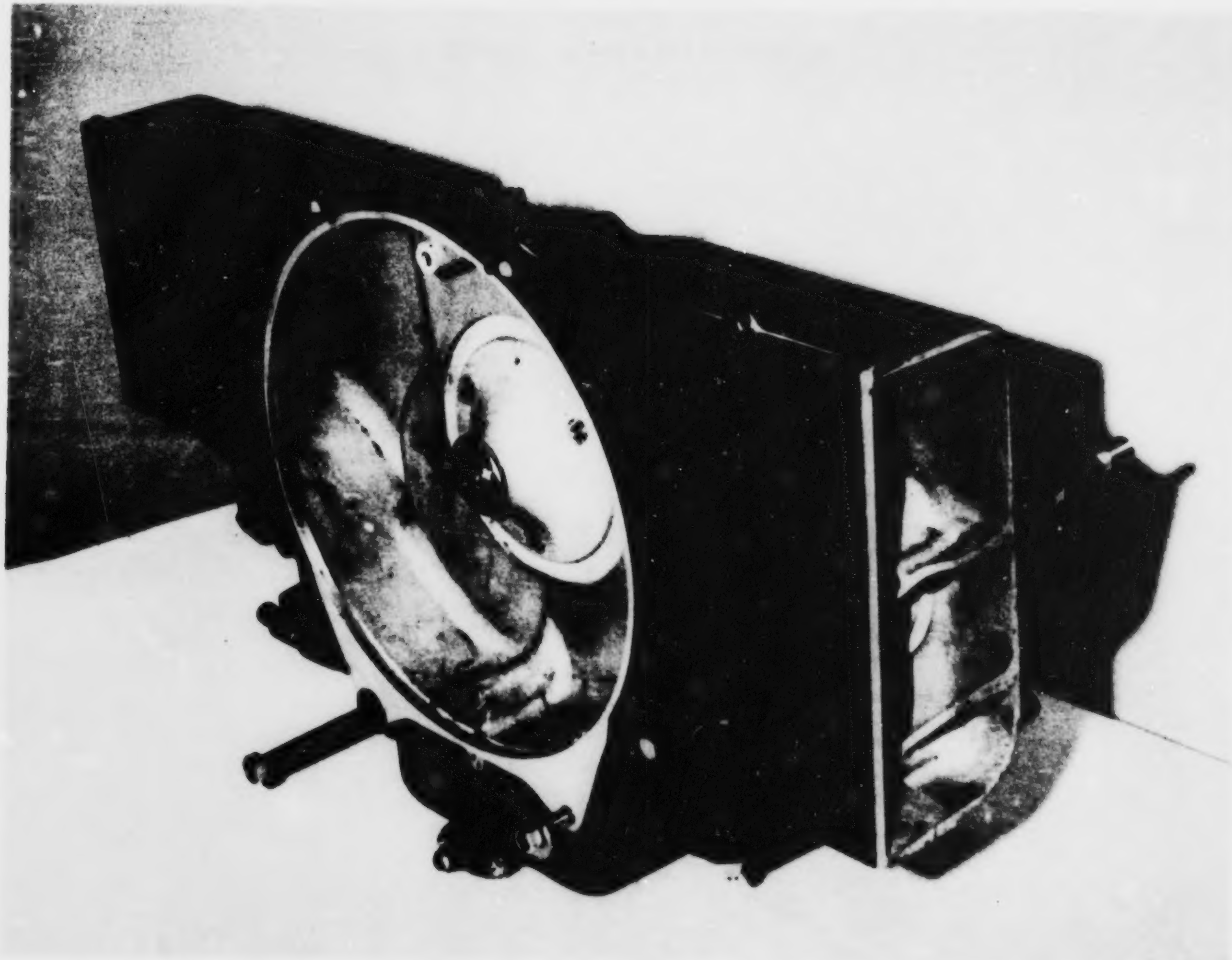

Figure 4. Rear View of Gearbox

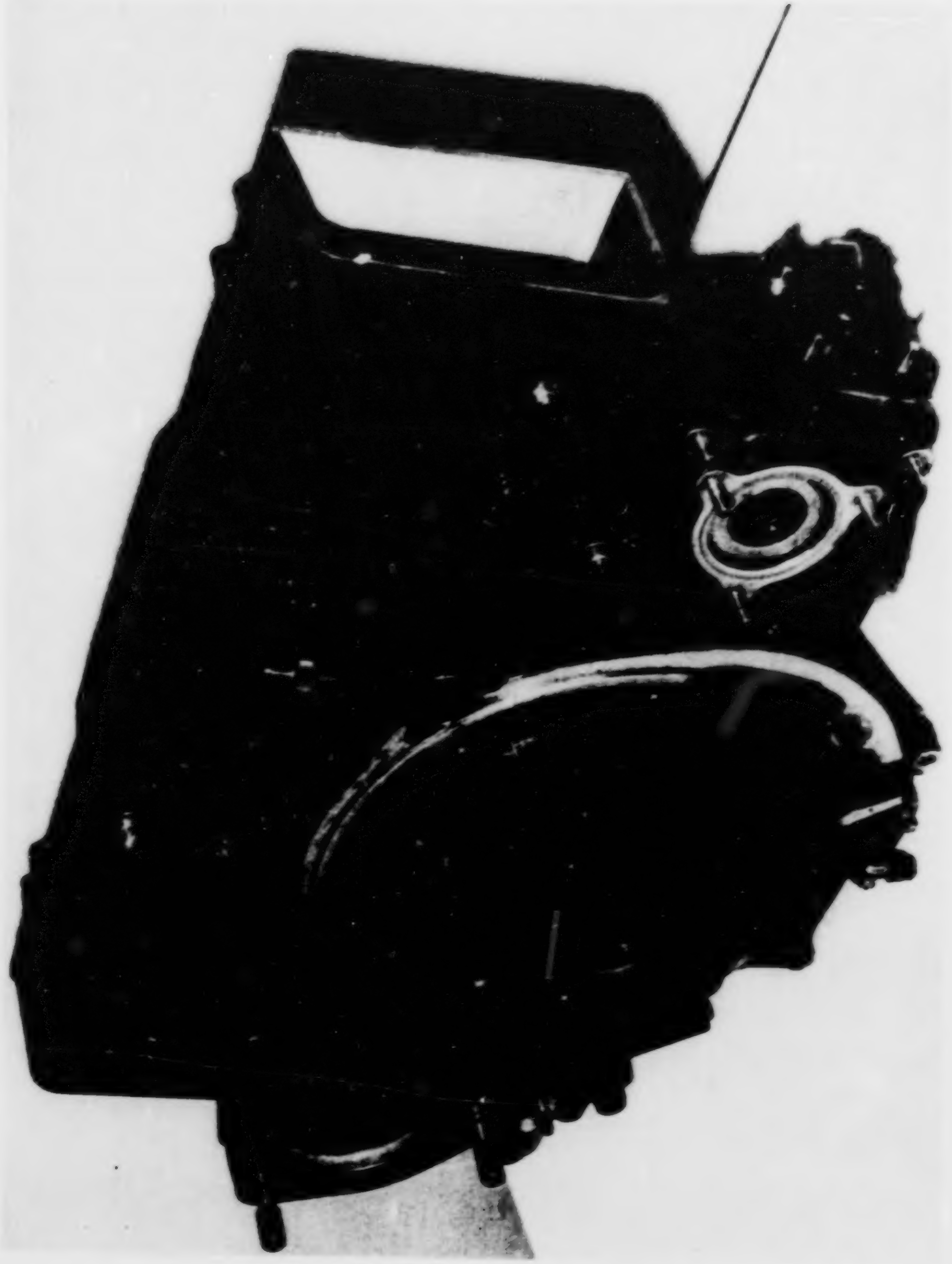

Figure 5. Front View of Gearbox

Accessories

All of the engine accessories are driven from the gas generator shaft and include:

a. Fuel pump and control

b. Oil pump

c. Air-oil separator

d. Starter

e. Regenerator drive

f. Oil cooler fan

In addition, a pulley, driven by the power output shaft, is available for driving automotive accessories; such as alternators, pumps, etc.

The fuel control is a hydromechanical control. The fuel pump, speed governor, and altitude compensator are contained in a single unit. Regenerator outlet temperature compensation is achieved by a separately mounted unit.

A centrifugal air-oil separator is incorporated into the first accessory reduction shaft. This separator removes the labyrinth seal leakage air from the gearbox without any measurable loss of oil. The engine oil pump is also integral with the gearbox.

Provisions are included on the engine gearbox to drive a squirrel cage fan for oil cooling. When this fan is used, it draws the oil cooler air directly from the engine inlet air duct.

Starting is accomplished by a conventional 12-volt automotive starter with the output drive modified. The normal pinion and overrunning clutch have been replaced by a male spline that is engaged by a standard starter solenoid during starting.

CONCEPTUAL ENGINE DESIGN

The very nature of an engine development program dictates that the prototype engine be continually in a state of change and improvement. Since the inception of this engine, numerous design changes have already been incorporated; and at the beginning of this economic analysis, varous additional refinements were in the conceptual stage and were scheduled for inclusion into the basic engine design. Although these changes primarily represent improvements in performance, certain advantages are also realized in the areas of weight reduction and producibility. It was decided; therefore, that to include these conceptual changes would not detract from the credibility of the study, but would upgrade the basic engine to a point where it realistically represents the 1975 state of the art for automotive gas turbine engines. For purposes of this study, the following design changes have been incorporated into the basic engine previously described.

Electronic Fuel Control

The hydromechanical fuel control used on the basic turbine engine lacks the flexibility needed to closely match acceleration fuel schedules to engine requirements. In addition, engine protective devices can easily be incorporated into an electronic fuel control system. For example, turbine inlet temperature, the parameter affecting engine life more than any other, can be monitored and modulated by the electronic control. Engine deterioration would then be evidenced by a decrease in power rather than by an increase in turbine inlet temperature. Moreover, an electronic control system can include provisions for automatic sequencing operations. Simplified and foolproof starting and operating characteristics are a definite requirement for wide-spread usage of automotive turbine engines.

Variable Power Turbine Nozzle

The incorporation of a variable power turbine nozzle, controlled by the electronic fuel control system, provides an improvement in engine response as well as a reduction in specific fuel consumption. By opening the power turbine nozzle area during acceleration, a larger pressure ratio is created across the gas generator turbine with a resulting increase in power available for acceleration. Conversely, the turbine nozzle area can be optimized to the reduced engine requirements when operating at a reduced or part-load condition. This design refinement improves specific fuel consumption by maintaining a high cycle temperature at part-load conditions. Unless the temperature is maintained, a rapid increase in specific fuel consumption occurs as power is reduced. This system also eliminates the power turbine by-pass value and actuator and the over-running clutch by providing power turbine nozzle areas and blade angles which minimize idle fuel flow and maximize engine braking. Particularly, a significant degree of engine braking is available at low and moderate vehicle speeds where the over-running clutch cannot provide such retardation.

Compressor Rotor, Turbine Wheels, and Regenerator Cores

This design change was incorporated to upgrade engine performance to 130 shaft horsepower from the original 80 shaft horsepower. This change, which makes the engine more suitable for automobiles in the 3,000 to 3,500 pound class, was accomplished simply by increasing the size of the compressor rotor, turbine wheels, and regenerator cores. The compressor rotor and both turbine wheels were enlarged 15% in diameter to accommodate the higher gas flow. The ceramic regenerator cores were also enlarged and redesigned for more efficient volume and surface areas.

Redesigned Engine Gearbox

The redesign and simplification of the engine gearbox was actually accomplished concurrently with the initial efforts of this economic analysis so that value engineering and producibility judgements could influence the evolving design. This modification was primarily a cost reduction effort; however, a reduction in weight is also realized. The incorporation of the variable power turbine nozzle eliminates the need for the overrunning clutch in the gearbox; therefore, several gears and bearings could also be eliminated. The roller bearings were replaced with sleeve bearings; and by relocating some of the engine accessories, various accessory gears could be eliminated.

Main Engine Case and Diffuser

An additional effort that proceeded concurrently with the beginning of this study was a redesign of the main engine case and diffuser. This redesign was made to permit substitution of aluminum die castings for the ductile iron housing and diffuser and to allow the use of the metal cores required by die casting. Some reduction in cost resulted from this modification along with a significant reduction in engine weight.

PRODUCIBILITY MODIFICATIONS

Throughout the iterative process of this analysis, value engineering concepts were used to influence the selection of alternate part configurations, arrangement, and materials to reduce the cost of high cost items. Because the prototype engine was not originally designed for high volume production, this concurrent value analysis effort was necessary in order to obtain a realistic manufacturing cost estimate for the production level of 1,000,000 units per year. The resulting changes to enhance engine producibility are as follows:

a. The machined steel gears in the engine gearbox are replaced with powdered metal gears.

b. The compressor diffuser is redesigned to be made as a two-piece aluminum die casting.

c. The stamped compressor rotor assembly cover is eliminated and made a part of the die cast diffuser cover.

d. The compressor rotor is redesigned to be made from a permanent mold centrifugal casting instead of an aluminum investment casting.

e. The diffuser radiant heat shield is redesigned to be made from one piece with the alloy content reduced.

f. Powder metal techniques are used to make the fuel distribution manifold in order to reduce machining.

g. The outer burner cover is made from 310 stainless steel instead of nickel base alloy.

h. The main case is redesigned, primarily to facilitate the extraction of metal cores, so that it can be made as an aluminum die casting.

i. The shaft design is modified to permit the use of cold extrusions.

j. The shaft is inertia welded to the compressor turbine.

k. The main bearing support is redesigned to eliminate separate spacers, crossover tubes, and oil drain castings. Powder metal parts are combined into a single part during the sintering cycle.

l. The main bearing oil drain is redesigned to eliminate the mounting flange, bellows, "O" rings, pressure bulkhead seals, and extra braze joints.

m. The exhaust diffuser is redesigned for simpler fabrication.

n. The exhaust housing cover subassembly operations are eliminated in favor of assembling on the final assembly line.

o. The regenerator covers are redesigned to permit stamped steel fabrication.

p. The regenerator seals are redesigned to eliminate the brazed bellows and to allow seam welding to the shoes.

q. The regenerator core drive is redesigned to utilize powder metal bushings of iron, copper, and graphite in place of ball bearings and retaining rings. The new design incorporates a split-tube core center; larger sprockets from stamped steel and smaller sprockets from powder metal; a stamped chain guard instead of the cast part; integral cast pillow blocks; and a tubular cross shaft, relocated from the top to the bottom of the engine to eliminate the idler sprockets and permit the use of a shorter drive chain.

The 1975 automotive turbine engine, incorporating the conceptual design changes and the producibility modifications, is illustrated in Figure 6. Table 1 summarizes the design point characteristics of this powerplant.

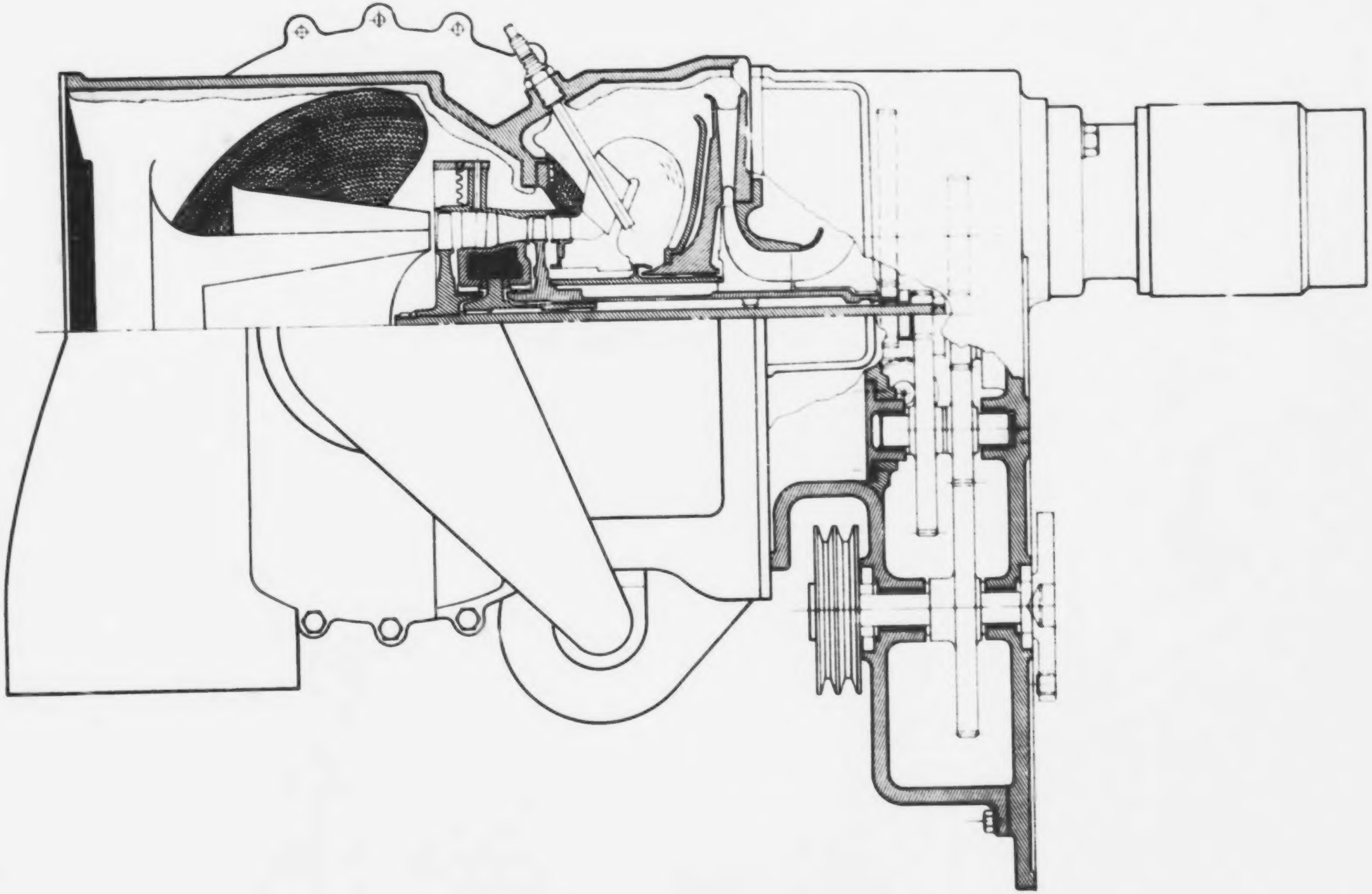

Figure 6. Williams Research 1975 Regenerative Automotive Turbine Conceptual Design Layout

TABLE 1. ENGINE DESIGN POINT CHARACTERISTICS

Ta	519° R
Pa	14.69 psia
HP	130 HP
SFC	.400
T3-T.I.T.	2360° R
Inlet Airflow (W1)	1.433 lb/sec
Inlet Airflow $(W1\sqrt{\theta_1}/\delta_1)$ Corrected to Comp. Inlet	1.462 lb/sec
P1/PA	.98
P2/P1 - Compressor Pressure Ratio	4.5
P2A/P2 - Cold Side Regenerator Pressure Ratio	.995
P3/P2A - Burner Pressure Ratio	.96
P3/P4 - Compressor Turbine Pressure Ratio	2.019
P4/P5 - Power Turbine Pressure Ratio	1.878
P6/P5 - Exhaust Duct Pressure Ratio	.94
P7/P6 - Hot Side Regenerator Pressure Ratio	.9515
P7/P8	1.00
T2	860° R
T2A	1683° R
T4	2045° R
T5	1796° R
T7	968° R
Q2 - Compressor Turbine Flow Parameter	1.059
Q4 - Power Turbine Flow Parameter	1.990
WL1/W1 - Labyrinth Seal Leakage	.01
WL2/W1 - Total Regenerator Seal Leakage	.05
WL3/W1 - Regenerator Carry-Over Leakage	.0078
HP_{1ext} - G.G. Shaft Friction & Engine Accessory Load	4.3 HP*
HP_{2ext} - P.T. Shaft Friction	2.6HP**
EC - Compressor Efficiency (Total to Static)	.81
ET1 - Compressor Turbine Efficiency (Total to Total)	.86
ET2 - Power Turbine Efficiency (Total to Total)	.85
EB - Burner Efficiency	1.00
ER - Regenerator Effectiveness	.885
Regenerator Geometry:	
Active Hot Side Frontal Area	242.7 in^2
Active Cold Side Frontal Area	114.0 in^2
Matrix Thickness	2.653 in.
Matrix RPM	13.26 rpm
Matrix Material	Cercor TM-2038

*HP_{1ext} consists of 1.7 HP which remains constant with gas generator speed and 2.6 HP which reduces with gas generator speed to the 2.6 power.

**HP_{2ext} consists of 2.6 HP which reduces with power turbine speed to to 2.6 power.

SECTION III

Initial Cost of Ownship

ASSUMPTIONS AND GROUND RULES

In addition to the guide lines specified by the terms of the contract, a number of supplementary assumptions and ground rules were established at the beginning of this study in order to provide a basis for estimating the initial cost of ownership of the 1975 preproduction engine.

Because the engine used for this analysis is a prototype engine in many respects, most of the components were originally designed to be manufactured within the Williams Research Corporation facilities utilizing the fabrication and assembly equipment available. Therefore, as this study progressed, numerous minor design changes were made to increase the producibility of the current engine components and to maximize the use of more common, less expensive raw material. Chipless machining processes were considered wherever possible to minimize the amount of material used. Parts fabricated through the use of powdered metal techniques were investigated and frequently substituted for parts cut from wrought material. These changes to the prototype engine are discussed in detail in Section II of this report.

It was postulated that all manufacturing processes specified for the components be in use today or at least demonstrated, but not necessarily at the production volumes required. Where possible, automobile production ground rules were then applied to these processes so that automated production lines and automatic transfer lines could be considered.

The turbine engine production level established for the manufacturing cost analysis was specified at 1,000,000 units per year by the contract. The probable automotive approach to meeting this requirement would be to provide for production line speeds accommodating 300 components per hour. This quantity is based on the common automotive industry practice of utilizing equipment having gross cyclic rates capable of producing the annual requirement in ten months, at 320 hours per month (based on two, 8-hour shifts per day, five days per week). When allowances are considered for down-time, tool changing, absenteeism, etc., this production rate is reduced by approximately 30% and the annual capacity becomes somewhat less than that required. However, because the equipment and personnel are fully utilized throughout most of the year, short term peak schedule requirements would be met by instituting temporary third shift or weekend overtime.

For those parts that can be produced at rates considerably in excess of 300 per hour, such as stampings, etc.; it was assumed that the applicable higher manufacturing rate would be used; and that the appropriate labor content for that rate would be applied. The cost of palletizing, storing, and delivering to the production lines would be considered an overhead cost. The following basic ground rules concerning direct labor and material were then established:

a. The manufacturing cost estimate would reflect only direct labor and material costs.

b. The labor rate to be used would be $4.50 per hour, or 7-1/2¢ per minute.

c. Current "Iron Age" mill prices for raw materials would be used.

Although most of the engine components lend themselves to standard automotive processing techniques and their material and labor content could be readily established, certain components require the services of specialty vendors. These components include the fuel control unit, ceramic regenerator cores, ignition system, bearings, and investment castings. Whereas one of the primary objectives of this study was to establish the labor and material content of the engine, the introduction of purchased parts would complicate the analysis unless the extraneous elements of overhead, general and administrative costs, and profit could be factored out of the vendor's quoted selling price. Therefore, certain assumptions were made regarding the method used by an automotive Original Equipment Manufacturer (OEM) to develop a quoted selling price. These assumptions are:

a. Typical automotive parts are comprised of 80% material cost and 20% labor cost.

b. Overhead rates are approximately 380%.

c. General and Administrative costs are 15%.

d. Division profit is 5%.

e. Corporate profit is 15%.

For example, an automotive part with a combined labor and material content of $1.00 would sell for:

$0.80	Material Cost	(80%)
0.20	Labor Cost	(20%)
0.76	Overhead	(380%)
$1.76		

$0.26	General and Administrative cost	(15%)
0.10	Division Profit	(5%)
0.32	Corporate Profit	(15%)
$2.44	Selling Price	

Therefore: Labor & Material x 2.44 = OEM Selling Price

or: Labor & Material x 0.41 x OEM Selling Price

Vendor selling prices factored in this manner for the combined material and labor content could be ratioed 80/20 for the material and direct labor cost elements, which then could be included in the part cost tabulation.

These factors were derived from various inputs. Procurement personnel at Williams Research with experience in the Automotive OEM field, our manufacturing cost estimators and process engineers who have been employed by automobile and automobile component producers and casual conversations with product cost estimators and sales personnel, currently in these fields, have been the chief sources of the data used. The final factors represent a composite of the information obtained from these various sources. A reasonably high level of confidence exists with regard to their accuracy as a result of the consistency and correlation we noted among the various sources. Additional verification work in this area is planned and the results will be published as a supplement.

Additional assumptions were required in order to extract the materials costs of aluminum die castings, air melt steel and alloy castings from their selling prices. The cost factoring for aluminum die castings was based on the assumptions that the ingot would cost $.25 per pound, that the sprue weight would be 20% of the total part cast weight, that oxidation and spillage losses would be 3%, that melting and holding costs would amount to $.03 per pound, that the sprue would be recoverable and its value would be equal to 50% of the original sprue weight cost. This factoring results in a material cost for aluminum die castings of $.312 per pound.

For air melt steel and alloy castings, the assumption was made that the raw material cost would be equivalent to the sum total of the weight of each constituent times the cost of that constituent in one pound of alloy. The sprue gate and riser would require an additional amount of alloy, equivalent to 50% of the total cast part weight, which would be recovered at 50% of the original value. Oxidation losses would amount to 5%. Foundry labor for charge make up, melting, and metal transfer is considered to be a part of the material cost and is estimated at $.03 per pound. The costs of pouring, operating the mold line, shaking out the castings, cleaning, and making cores are estimated at an additional $.03 per pound and are treated as direct labor (not included as part of the raw material cost). Using these assumptions, the material cost for steel and alloy castings would be:

Material Cost per Pound = Total per Pound Cost of Alloys x 1.32 + $.03

For example, a Hastelloy W casting weighing 10 pounds and comprised of:

Cr	5%	X	$1.15	=	$ .057
Ni	60%	X	1.27	=	.762
Mo	25%	X	3.73	=	.932
Co	1%	X	2.30	=	.023
Fe	5.5%	X	.06	=	.003
					$1.777 Total Alloy Cost per Pound

Then:

Metal Cost for Casting (10 lbs.)	$17.77
Metal Cost for Sprue (50%)	8.88
Oxidation and Spillage (5%)	.89
	$27.54
Sprue Credit (50% of original sprue wt.)	4.44
	$23.10
Labor for Melting, etc.	.30
Material Cost for Finished Casting	$23.40

By formula:

$1.777 x 1.32 + $.03 = $2.34/lb.

The direct labor content for the finished casting would be $.30 (for pouring, shaking out the castings, cleaning, etc.) plus the cost of machining operations.

APPROACH TO ANALYSIS

Figure 1 outlines the basic logic and sequence of the cost estimating tasks. After establishing the fundamental rules and guide lines to be used throughout the manufacturing cost analysis, the basic engine design and the engine parts list were updated to include the various engine refinements based on results from other Williams Research engine developments. Essentially, these refinements consist of an electronic fuel control, a variable area power turbine nozzle, larger regenerator cores, redesigned gear box, an aluminum die cast main case and diffuser, etc.

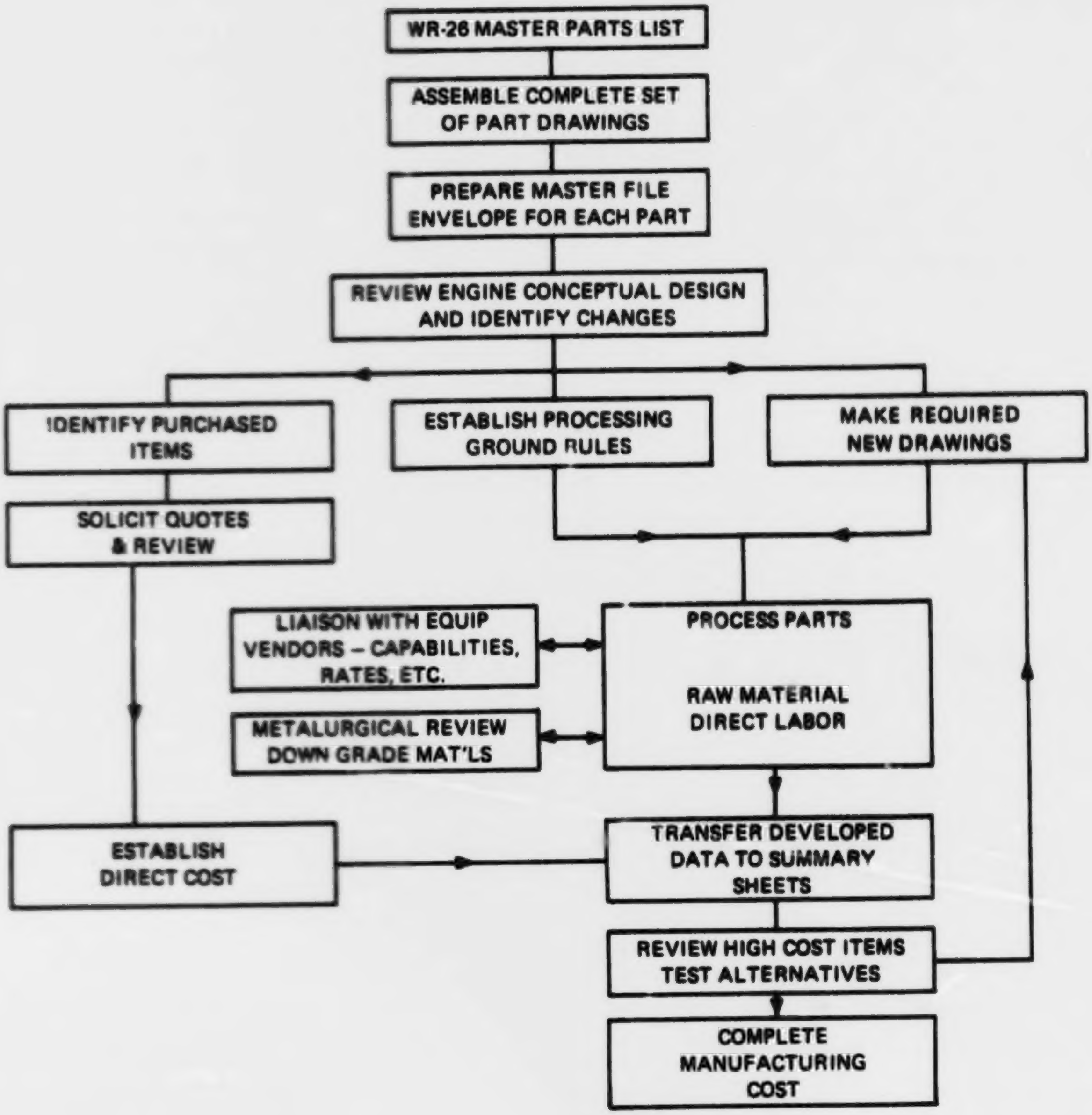
WR-26 MASTER PARTS LIST
ASSEMBLE COMPLETE SET OF PART DRAWINGS
PREPARE MASTER FILE ENVELOPE FOR EACH PART
REVIEW ENGINE CONCEPTUAL DESIGN AND IDENTIFY CHANGES
IDENTIFY PURCHASED ITEMS
ESTABLISH PROCESSING GROUND RULES
MAKE REQUIRED NEW DRAWINGS
SOLICIT QUOTES & REVIEW
LIAISON WITH EQUIP VENDORS – CAPABILITIES, RATES, ETC.
METALURGICAL REVIEW DOWN GRADE MAT'LS
PROCESS PARTS
RAW MATERIAL
DIRECT LABOR
ESTABLISH DIRECT COST
TRANSFER DEVELOPED DATA TO SUMMARY SHEETS
REVIEW HIGH COST ITEMS TEST ALTERNATIVES
COMPLETE MANUFACTURING COST

Figure 7. Manufacturing Cost Estimating Flow Diagram

Drawings for each detail part contained in the engine were assembled into a master file. A process sheet was also completed for each part and for each subassembly and was filed with the drawings. The evaluation of each detail part and subassembly for the predetermined production rate of 300 parts per hour was accomplished by outlining the required machining operations and then deciding whether the part could be made on standard high production multi-spindle equipment. If the part could not be made on multi-spindle equipment, it was assumed that a special machine or machines, usually of the transfer type capable of meeting the required production rate, would be used. Utilizing manufacturing process engineers, experienced in both high production automotive and turbine engine technologies, a judgement was made concerning the number of men required and the appropriate labor minutes per part for the operation. Table 2 includes the process sheets for all engine parts with direct cost in excess of $0.50 per engine. These items represent 91% of the total direct labor cost of the engine.

Each drawing and its corresponding process sheet were then reevaluated to ascertain high cost items. As the high cost areas were defined, informal engineering meetings were held to propose and evaluate alternate designs, processes, and materials. When a solution was found, an engineering layout was prepared, if required, reflecting the redesigned part; a new or revised process sheet was completed; and the engine parts list was revised to incorporate the changes. As the processing details evolved, the applicable data; such as material, part weight, material cost and labor cost, etc.; were itemized on the Manufacturing Cost Estimate Tabulation Sheets, Table 2.

Vendors were contacted and their quotes obtained for the purchased items at the production level of 1,000,000 units per year. These quotes were factored to obtain the labor and material content, which was then included on the tabulation sheets.

The final assembly of the turbine engine was processed assuming a contemporary automotive mass production environment with existing equipment and typical unskilled workers. No assumptions were made regarding the availability of equipment not yet in existence, and only a nominal degree of assembly automation was visualized.

The analysis of past experience in the bench assembly of turbine engines under R&D conditions led to the conclusion that the most time consuming factor in assembly operations is the dimensioning required to prevent a biased stacking of the tolerances of moving parts. To make assembly on a production line possible, components can be machined in accordance with predetermined tolerances and accepted into the final assembly feeder system on a go or no-go basis. This is the current procedure used in the manufacture of piston engines.

A detailed time and motion study was made using Methods-Time-Measurement (MTM) data, which is generally accepted as a statistically stable time-methods unit. This motion study determined the work content in the assembly operations of the turbine engine, which could then be extended to manpower load and cost. The number of work

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET

400-401-900

Williams Research Corporation

28005 **ITEM NO.**

PART NAME Regen. Housing (Main Case)

PROCESSED BY R.T.H.

QUANTITY/ENG. 1

ENGS./YR. 10^6

PAGE 1 **OF** 1

MATERIAL Aluminum Alloy A214

FORM Die Casting

SIZE

WEIGHT 30.0

MAT. COST/ENG. $9.36

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
	Mat. cost per formula -	.312 X 30.0 = 9.36					
	Casting	10 men		2.0			
	Trim and inspect	2 men		.4			
	Heat treat	3 men		.6			
	Machine (transfer)	3 men		.6			
				3.6			
				X .075	.27	Labor	
					9.36	Material	
					$9.63	Total	
							$9.63 ea.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079A-1

Williams Research Corporation

ITEM NO. ______

PART NAME Flange, Power Turbine Mounting

PROCESSED BY Fielek

QUANTITY/ENG. 1

ENGS./YR. 10^6

MATERIAL 310 Stainless Steel

FORM Coil

PAGE 1 **OF** 1

SIZE .060 X 10 X 10

WEIGHT 1.74

MAT. COST/ENG. .96

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Blank, form, draw and pierce - auto. unload	Transfer press	(1200/Hr.)	.050			
20	Clinch 6 bolt support bushings						
	Hopper feed bushings		1200/Hr.	.050			
30	Transfer to next assy.						
		Total		.1000 x .075		.0075	Labor
						.96	Material
						$.9675	
							$.9675

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079-3 Modified

Williams Research Corporation

ITEM NO. ________

PART NAME Shroud - Outer

PROCESSED BY H.S.

QUANTITY/ENG. 1

ENGS./YR. 1^6

PAGE 1 **OF** 1

MATERIAL Hastelloy X

FORM Cast

SIZE ________

WEIGHT 2.6331 Lb. @ $2.34/Lb.

MAT. COST/ENG. $6.1615

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
	Base material cost	2.34 X 2.6					
10	Chuck - face 4 lugs	Multi spindle					
	Bore I.D. for turbine blade,	New Britain chucker	360/Hr.	.167			
	rough bore for moving vanes.						
	Face end to length.						
	1 man - 2 machines						
20	Drill 17 places for vanes	17 spindle woodpecker	500/Hr.	.120			
	and ream.	Shuttle fed to ream					
	1 man - 3 drills -	facility					
	1 ream station						
	Chuck - bore I.D. for						
	compressor turbine	W & S Multi spindle	360/Hr.	.167			
	wheel - face inner shroud	chucker					
	and outer shroud						
	1 man - 2 machines						
				.454 X .075 =		.03405	Labor
						6.1615	Material
					Total	6.19555	
							$6.1955

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079A-11

11 ITEM NO. **Williams Research Corporation**

PART NAME Vanes – Variable Nozzle

PROCESSED BY Fielek

QUANTITY/ENG. 17

ENGS./YR. 10^6

MATERIAL Hastelloy "X"

FORM Coiled Wire

PAGE 1 OF 1

SIZE .043" Cross Sect. Area

WEIGHT .020# (Vane + Shaft)

MAT. COST/PC $.045

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Combination Hot & Cold						
	Rolling Line to form &	Similar to razor blade					
	grind air foil cross section	line					
(A)	Line Splits into press forming	All automated material					
	& cut off to proper length &	handling and orientation					
	desired radii on ends	Auto unload					
(B)	Parallel cold header line cuts		6000/Hr.	.010	.00075	Labor	
	off, forms and sizes shaft				.04500	Material	
					$ .04575	Each X 17/Eng. =	
(C)	Shaft is capacitor discharge						
	welded to vane						$.777
(D)	Drill roll pin hole in shaft						
20	Transfer to next assy.						
							$.777/Eng.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079A-14

P.M.

Williams Research Corporation

ITEM NO. ______

PART NAME Segment – Gear Drive Vane

PROCESSED BY H.S.

QUANTITY/ENG. 17

ENGS./YR. 1^6

PAGE 1 **OF** 1

MATERIAL 310

FORM PM

SIZE ______

WEIGHT .04 each = @ $.70 Lb.

MAT. COST/EACH .028

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Briquette - form	Stokes press					
	1 man - 6 presses @ 20 per minute		7200/Hr.	.0083	.0006225		
	Auto eject to conveyor furnace						
20	Sinter eject to auto cycle						
30	Hot coin	knuckle press					
		Automatic feed	7200/Hr.	.0083	.0006225		
		shuttle into dies					
40	Heat Treat	Automatic furnace					
50	Drill and ream vane	Hand load	5450/Hr.	.011	.000825		
	Stem hole and Roll	Automatic feed					
	Pin cross hole	Automatic cycle					
		Multi station					
		Drill and ream machine					
60	Automatic deburr				$.002 Each	Labor	
					.028	Material	
					.030	Total Each	
						X 17 Blades	= $.51
							$.51/Eng.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079A-2 Modified

Williams Research Corporation

2 **ITEM NO.**

PART NAME Shroud - Inner

PROCESSED BY H.S.

QUANTITY/ENG. 1

ENGS./YR. 10^6

PAGE 1 **OF** 1

MATERIAL Hastelloy X

FORM Casting

SIZE

WEIGHT .2901 @ 2.25 lb.

MAT. COST/ENG. .65

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
	Cast Mtl.	base cost 1.50 lb.					
	Additional	mtl. cost .75 lb. (Mtl.	Penalty)				
	Gross cast mtl. cost	2.25 Net - Variance due to wgt.					
10	Foundry labor @	.04 lb.		.0150			
20	I.D. Chuck	Multi Spindle					
	Spherical form	Horiz. chucker	360/Hr.	.0167			
	Face lugs.	Multi cutters					
	150 SFM						
30	Clean up opp.	Blanchard					
	Face - 20 at a time	Grinder	400/Hr.	.1500			
40	Drill Lugs	Multy station					
		Multy spindle w/	600/Hr.	.1000			
		Drill hds.					
50	C'Less Grind OD	Magazine Feed					
	Contour-Spherical	Chute Guide Rails					
		C'Less Grinder	360/Hr.	.0167			
		Total		.2834	.0213		
					.0363		
				Material	.6500		
					$ .6863		
						Total	$.6863

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17481 **ITEM NO.**

Williams Research Corporation

PART NAME 17481 Flange - Rear Bearing Housing

PROCESSED BY ____

QUANTITY/ENG. One

ENGS./YR. 10^6

PAGE 1 **OF** 1

MATERIAL H-11 Tool STL.

FORM Wire - \$.58/lb.

SIZE Rectangular Wire

WEIGHT .225

MAT. COST/ENG. .13

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Cut off & hoop	Shear & Coil 350/Hr.		.17			
Butt weld	Butt welder		.17			
Trim Flash	Flash trimmer		.17			
Size	Press		.17			
Anneal 1¢/lb.	Furnace		-	.002		
Pickel & Phos. 2¢/lb.	Tanks		-	.004		
Back Extrude	Press		.17			
Lathe Turn	Lathe		.17			
Heat Treat 2¢/lb.	Furnace		-	.004		
			1.02	.076		
				.086	Labor	
Drill holes at assy.				.130	Material	
				.216	Total	
						\$.216 ea.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17236 **ITEM NO.**

PART NAME Flange — Nozzle Mtg.

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL 310 S.S.

FORM P./M.

SIZE ____

WEIGHT 1 lb. est @ .75 lb.

MAT. COST/ENG. $.75

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Compact - Briquette	Stokes	200/Hr.	.300			
20	Sinter	Auto. Furnace					
30	Press - Coin	Coining Press	400/Hr.	.150			
40	Drill (6) .124 Dia.	Multi Spindle					
	Holes	Drill Press w/					
		Drill Heads and	300/Hr.	.200			
		Tapping Heads					
		Auto. Eject at Tapping					
		Auto. Transfer Tooling					
50	Deburr	Wheelabrator	800/Hr.	.075			
				.725			
60	Inspect						
					$.054375		
	NA 17779				.75		
					.804375		
							$.8043

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17337 ITEM NO.

Williams Research Corporation

PART NAME Flange Burner Mounting

PROCESSED BY H. N.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 OF 1

MATERIAL 321 Cent. Cstg.

FORM Cstg.

SIZE Cstg.

WEIGHT 1.085

MAT. COST/ENG. $.65

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Foundry Labor .04 lb.						
Anneal						
Turn and Bore			.2			
Drill and C'Bore			.2			
			.4	.030		
				$ .073	Labor	
				$ .650	Material	
				$ .723		
Alternate Method for 300/Hr.						
Use Butt Welded Ext. Ring Rolled						
						$ .723

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17723 ITEM NO.

Williams Research Corporation

PART NAME Outer Wall Burner

PROCESSED BY B.J.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

MATERIAL Hastelloy "X"

FORM Sheet

PAGE 1 **OF** 1

SIZE 12 x 12 x .031

WEIGHT 1.32 @ $2.25 lb.

MAT. COST/ENG. $2.97

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
	Blank			.1			
	Form			.2			
	Trim Lg. End			.2			
	Pierce 15 Slots	3 Position Spec. Press		.1			
	Pierce 15 Holes	3 Position Spec. Press		.1			
	Pierce 15 Holes	3 Position Spec. Press		.1			
	Blank Small End			.1			
	Anneal Vacuum						
	Restrike			.1			
	Extrude 15 Stolte Holes	3 Position Spec. Press		.1			
	Extrude 15 Holes	3 Position Spec. Press		.1			
	Extrude 15 Holes	3 Position Spec. Press		.1			
	Slot 30 Places	3 Position Spec. Press		.1			
				1.4	$ .105	Labor	
					2.97	Material	
					$3.075		
							$3.075

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17755-E-10092 ITEM NO.

Williams Research Corporation

PART NAME Vane - Burner

PROCESSED BY Shost

QUANTITY/ENG. 15

ENGS./YR. 10^6

PAGE 1 OF 1

MATERIAL Hastelloy "X"

FORM Tubing

SIZE 15/16 Dia. OD X .021 Wall Turbine

WEIGHT .01587 LB. @ $2.50/lb.

MAT. COST/ENG. .04

OPERATION		MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
		Random Length					
10	Form in multiples	Upsetting					
	1-1/2 in. dev. length	Facility - (4)					
	30°	Slide typical	2400/Hr.	.0250			
	40 SPM						
20	Index - Locate by						
	OP. #10 contoured	(4) Slide upsetter					
	30° shoulder	or equiv.					
	Form 20° shoulder						
	35 SPM	1/2 man	2100/Hr.	.0143			
30	Automatic locate -	Punch press					
	- Notch Tabs -	W					
	cut off 20° & 30° &	Notching Die					
	form air foil	&					
	35 SPM	Locators					
		1/2 man	2100/Hr.	.0143			
	(1 man runs 2 presses)						
				.0536			
				Labor	.00402		
				Mt.	.04		
				Total	.044		
						Each	$.044

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17725 **ITEM NO.**

PART NAME Inner Wall - Burner

PROCESSED BY H. N.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL Hastelloy "X"

FORM Strip

SIZE 8 x 8 x 044

WEIGHT .822 lb @ 2.25 lb.

MAT. COST/ENG. $1.8495

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Form			.1			
Pierce (5) Slots	3 Position Press					
(3 Times)			.1			
Trim Lg. End			.1			
Anneal						
Restrike			.1			
Trim Small End			.1			
Extrude	3 Position Spec. Press		.1			
Pierce 30 .052 Holes	3 Position Spec. Press		.1			
Lance 15 Louvers	3 Position Spec. Press		.1			
			.8	$ .060	Labor	
				1.8495	Material	
						$1.9095

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17752 ITEM NO.

Williams Research Corporation

PART NAME Primary Plate

PROCESSED BY R. T. H.

QUANTITY/ENG. 1

ENGS./YR. 10^5 & 10^6

PAGE 1 OF 1

MATERIAL Hastelloy "X"

FORM Strip

SIZE 8 x 8 x .025

WEIGHT .475 @ 2.25/lb

MAT. COST/ENG. $1.0687

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Blank			.1			
Form			.1			
Pierce 240 .052 Hole						
and 18 .093 Holes						
Anneal			.2			
Restrike			.1			
Shear and Form Louvers			.2			
			.7			
				$ .0525	Labor	
				1.0687	Material	
				$1.1212		
					Each	$1.1212

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

E-10079A-15 ITEM NO.

Williams Research Corporation

PART NAME Gear-Ring – Vane Drive

PROCESSED BY H. S.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

MATERIAL 310 St. STL

FORM P. M.

PAGE 1 **OF** 1

SIZE 7-7/8 O.D. X 7-1/4 I.D. x 3/8 LG (for fig. **WEIGHT** .904 lb @ .70 lb

MAT. COST/ENG. .5629

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Compact - Briquette	Stokes Presses	500/HR	.12			
20	Sinter	Furnace					
30	Cold Form	Knuckle Press	800/HR	.075			
			Total	.195			
				Labor	.014625		
				Material	.5628		
					.577425		
							$ .5774

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17549 **ITEM NO.**

Williams Research Corporation

PART NAME Sleeve Compressor Turbine Shaft

PROCESSED BY P. J.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL 17-4 P H

FORM Tube

SIZE .25 Wall X 2.25 OD X 4.25

WEIGHT 1.93# @ .83 lb

MAT. COST/ENG. $1.602

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Turn, Bore and Cutoff			.2			
Drill			.2			
Mill			.2			
Grind			.2			
Turn Seals			.2			
			1.0			
		Labor		.075		
		Material		1.602		
			Total	1.677		
						$ 1.677

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17618 **ITEM NO.**
PART NAME Burner Cover
PROCESSED BY H. S.
QUANTITY/ENG. 1
ENGS./YR. 1 Million
MATERIAL Hastelloy X
FORM Strip
PAGE 1 **OF** 1
SIZE .025 x 13 x 13.0
WEIGHT .605 @ $2.25 lb
MAT. COST/ENG. $ 1.361

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Form and Blank I. D.	Mech. Press	600/HR	.1			
Pierce .052 Holes	Press	600/HR	.1			
Anneal						
Restrike	Press w/ Form Die	600/HR	.1			
Lance and Form Louvers		600/HR	.1			
Trim LG. End		600/HR	.1			
			.5			
			Labor	$ .0375		
			Material	1.361		
				1.3985		
					Each	$ 1.3985

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17226 **ITEM NO.**

Williams Research Corporation

PART NAME Heat Shield - Diff - and Burner

PROCESSED BY H. S.

QUANTITY/ENG. 2

ENGS./YR. 10^5 & 10^6

PAGE 1 **OF** 1

MATERIAL 321 SS

FORM Strip

SIZE .019 x 10.600 x 10.600

WEIGHT .6233 @ .70 lb.

MAT. COST/ENG. Each $ .4363

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Blank and Draw	)		.066			
Trim and Pierce C-Hole	) 900/hr.		.066			
Inspect - Pallatize	)		.066			
			.198			
				$ .0148	Labor	
				.4363	Material	
				$ .4511		
						$ .4511

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17586 **ITEM NO.**

PART NAME Fuel Manifold

PROCESSED BY H. S.

QUANTITY/ENG. 1

ENGS./YR. 10^6

PAGE 1 **OF** 1

MATERIAL 41055 PM

FORM P. M.

SIZE 3.620 x .715 x 2"

WEIGHT 3.808

MAT. COST/ENG. $1.33

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Press (2 Pcs.)			.2			
Sinter			-			
Face & Bore			.2			
Drill			.2			
Drill & C' Bore			.2			
Drill & Tap			.2			
			1.0	.075	Lbr.	
				1.33	Mtl.	
			Total	$1.405		$1.405

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

23057 **ITEM NO.**

PART NAME Diffuser

PROCESSED BY R. T. H.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL Aluminum Alloy A214

FORM Die Casting 5. lbs @ . 312 = $1. 5625

SIZE

WEIGHT 5. 0

MAT. COST/ENG.

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Die Cast in Two Pieces – Wedge Type Vanes - Bolt on Top Cover						
Melting and Holding Cast = . 03/lb = $. 15						
Body						
Die Cast - 1 Man-2 Mach @	45/hr		. 667			
Trim			. 200			
Machine			. 200			
Anodize			. 400			
Cover:						
Die Cast			. 667			
Trim			. 200			
Machine			. 200			
Anodize			. 200			
Assemble:						
Insert Studs			. 200			
Place Cover			. 200			
Place & Torque Nuts			. 200			
			3. 334			
				$. 250	Labor	
				1. 5625	Material	
				$ 1. 8125		
						$ 1. 8125

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17559 **ITEM NO.**

PART NAME Turbine Wheel - Proof Spin and Machine

PROCESSED BY Fielek

QUANTITY/ENG. 1

ENGS./YR. 1 million

MATERIAL Make from 17127 Sketch

FORM Casting 17127

PAGE 1 **OF** 2

SIZE In-713-LC 17563

WEIGHT 1.8 lb.

Purchased **MAT. COST/ENG.** $17.4928

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Grind hub ends flat	Bendix Besley	600/hr.	.10			
	and parallel-automatic	Double vert. spindle					
	sizing-manual load and	Wet disc grinder					
	unload						
20	Grind rims parallel and	Double vert. spindle	600/hr.	.10			
	square to hub.	Wet disc grinder					
	Auto. sizing - manual						
	load and unload						
30	.052-.053 drill 16 holes	Double station	600/hr.	.10			
		Drilling machine					
40	Bore I.D.	4 spindle boring	200/hr.	.30			
		mach.					
		1 man-2 machines					
50	Burnish for size and	Carbide ball	600/hr.	.10			
	R.M.S. finish	burnisher					
60	Spin test at 83,000 RPM	Test Stand	60/hr.	1.00			
	for 1 minute	1 man - 2 stands			$17.4928 material		
				Labor	.1425		
					$17.6353		$17.6353

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17559 **ITEM NO.**

Williams Research Corporation

PART NAME Turbine Wheel - Proof Spin and Machine

PROCESSED BY Fielek

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 2 **OF** 2

MATERIAL Make from 17127 Sketch

FORM Casting 17127

SIZE In-713-LC 17563

WEIGHT 1.8 lb.

MAT. COST/ENG. $17.4928

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
70	Zyglo Inspect and	Magnaflux Setup	300/HR	.20			
	In Line Wash						
80	Transfer to Next Ass'y						
	n/a 23069						

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Modified

17328 **ITEM NO.**

Williams Research Corporation

PART NAME Nozzle Ring - 1st Stage

PROCESSED BY H. S.

QUANTITY/ENG. 1

ENGS./YR. 10^6

MATERIAL INC 713-LC (17127)

FORM Casting - Purchased

PAGE 1 **OF** ___

SIZE ______

WEIGHT 1.168 lb.

MAT. COST/ENG. $9.43

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Drill (6) holes	Multi spindle press	360/Hr.	.167			
	6 per min.	w/ 6 drill heads					
20	Clean up lug face for	Automatic cycle					
	bolt heads	vert. spindle grind					
	5 per min.						
			300/Hr.	.200			
30	Grind 3.753 dia. and						
	lug face						
	3 per min.	Grinders	180/Hr.	.333			
			Total	.700	.0525		
			Purchased Casting		9.43		
					9.4825		
						Total	$9.48

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17562 **ITEM NO.**

Williams Research Corporation

PART NAME Wheel - Power Turbine

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR. 1,000,000

PAGE 1 **OF** 2

MATERIAL INC 713 LC

FORM Casting

SIZE Purch. 17179 Casting

WEIGHT 2.73 lb. - 130 HP

MAT. COST/ENG. 18.8253

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Grind Ends	Opposed Spindles					
	Parallel	Grinder					
	Automatic Sizing	Besley or equiv.					
	Magazine feed						
	1 man 3 machines	Auto eject -	600/Hr.	.10			
		Chute to					
		Next order					
20	Bore & chamfer	Excello 4 spindle					
		Boring machine					
	1 man 2 mach.	Automatic sizing	200/Hr.	.30			
		A					
30	Grind both hub diam-						
	eters & rim dia. & edges	Automatic chute					
	locate by I.D.	loader - dual wheel					
		grinders					
	1 man 3 machines	Landis type					
	Fach @ 150 Hrly	Automatic sizing	450/Hr.	.133			
		& wheel dressers					
40	Flake form grind	Grinder equipt.					
	U Grooves to clean up	w/form disc.					
	minimum	Diamond wheels					
	1 man - 5 machines		200/Hr.	.30			
	40 per						
						continued .	. . . . . .

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17562 ITEM NO.

Williams Research Corporation

PART NAME Wheel - Power Turbine

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR.

MATERIAL

FORM

PAGE 2 OF 2

SIZE

WEIGHT

MAT. COST/ENG.

OPERATION		MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
50	Drill 16 holes thru	Automatic 16 spindle					
	hub to center	Drilling facility					
	1 man runs 5 machines						
	@ 30 hrly.						
			150/Hr.	.40			
60	Ream & size bore	Carbide ball com-	400/Hr.	.15			
		bination					
		Broach & ball sizing					
		automatically					
		Fed. broach					
		Facility shuttle					
		Feed - auto eject					
70	Slush Deburr & wash						
80	Balance & Spin test	Test Stand					
		Facility w/	90/Hr.	.67			
	1 man-3 stands	Balance equipment					
90	Zyglo inspect		300/Hr.	.20			
				2.253	$.1689 Labor		

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

30176-01 **ITEM NO.**

PART NAME Shoe - Core Sealing - Hi-Pressure

PROCESSED BY Shosh

QUANTITY/ENG. 2

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL SAE-347 Alt 430 St. Stl

FORM Strip

SIZE #13 GA. (.094)

WEIGHT .5514 lb. @ .65 lb.

MAT. COST/~~STOCK~~ Ea. Pc. .3584

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
	Stamp Component Parts						
		Press From					
	Detail A	#30099-1 and 4	1800 Hr.				
	Detail B		3600 Hr.				
	Detail C		1800 Hr.				
	1 Man 3 Presses	(3) Die Sets		.0333			
20	Sub Assemble and	Welding Facility					
	Butt Weld 4 Joints	Automatic					
	Automatic Scarf	Shuttle Fixtures	360 Hr.	.160			
		W Scarf Die					
30	Serrate Bonding	Serration Die					
	Surface	Press	360 Hr.	.160			
40	Anneal and Straighten	Radiant Furnace					
		Controlled Atmosphere					
				.3533			
					$.02649	Labor	
					.3584	Material	
					.38489	Each	
							$ .38489

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Layout 397

17106 M ITEM NO.

Williams Research Corporation

PART NAME Gear - 1st Red. Pwr Train.

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR. 1 Million

MATERIAL SAE-8640

FORM P.M.

PAGE 1 OF 2

SIZE .75 face x 5.1 o. dia x 1.0 i. dia x .38 web

WEIGHT 3.8 lb @ $ .145 lb.

MAT. COST/~~ENG.~~ Ea. $ .551

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Press- Compact	Stokes HiSpeed	300 Hr.	.200			
	1 Man-2 Mach @ 150 Hrly.	Press					
20	Sinter	Automatic					
	Air Cool	Furnace					
30	Cold Restrike	Knuckle Press	400 Hr.	.150			
		Mag. Load					
40	Heat Treat	Holecroft Furnace					
	Rc "C" 32-35	Oil Quench Tanks					
50	Magnaflux Inspect	Automatic	400 Hr.	.150			
	and Load on Conveyor	Testing Facility					
	Hook						
60	Finish Bore	Mag. Feed Excello	360 Hr.	.168			
		Head Boring					
	1 Man-2 Mach @ 180 Hrly	Facility w Sizing					
		Equipment					

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Layout 397

17106 M ITEM NO.

Williams Research Corporation

PART NAME ____ PROCESSED BY ____

QUANTITY/ENG. ____ ENGS./YR. ____

PAGE 2 OF 2

MATERIAL ____ FORM ____

SIZE ____ WEIGHT ____ MAT. COST/ENG. ____

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
70	Finish Broach	Colonial Triple Hd.					
		Broach Mach w/					
		Positioning and					
		Loading Facility	400/Hr.	.150			
80	Shave	Gear Shaver					
	1 Man-2 Mach @ 125 Hrly		250/Hr.	.240			
90	Wash						
100	Tuff Tride	Furnaces-Tanks					
	2. Hours	Quenching					
110	Lap	Lapping Facility	200/Hr.	.300			
	1 Man-2 Mach @ 100 Each	Automatic Load and					
		Unload					
120	Wash			1.358	.10185		
					.551		
130	Inspect						
					.65285		
	NA 397-000						
							$ .6528

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

17104 M **ITEM NO.**

PART NAME Gear - Acc Drive

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 2

MATERIAL SAE 8640

FORM P.M.

SIZE 6.0 o.dia x 1.0 i.dia x .75 face x .38 web

WEIGHT 5.2 lb @ .145 lb

MAT. COST/[illegible] $ .754

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Press Briquette	Stokes	300 Hr.	.200			
	1 Man-2 Mach @ 150 Hr.						
20	Sinter	Furnace					
30	Restrike - Coin	Press	400 Hr.	.150			
40	Heat Treat Core	Holecroft Furnace					
	Rc "C" 32-35	Facility					
50	Magnaflux Inspect	Magnaflux Facility	400 Hr.	.150			
		w Conveyor Facility					
60	Finish Bore	Heald Boring					
		Facility - Automatic					
	1 Man-2 Mach @ 150 Hr.	Sizing Equipt. and	300 Hr.	.200			
		Part Loading and					
		Unloading					

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17104 M ITEM NO.

Williams Research Corporation

PART NAME ______ PROCESSED BY ______

QUANTITY/ENG. ______ ENGS./YR. ______ PAGE 2 OF 2

MATERIAL ______ FORM ______

SIZE ______ WEIGHT ______ MAT. COST/ENG. ______

OPERATION		MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
70	Broach Spline	Colonial Dbl Ram	350/Hr.	.171			
		Vert Broach w/					
		Load and Unload					
		Facility					
80	Shave Gear Teeth	Mich Gear Shaver	350/Hr.	.171			
90	Wash - Dry	Automatic					
100	Tuff Tride	Heat Treat Tanks					
	2 Hours	Quenching Facility					
110	Lap	Mich Tool Lap	350/Hr.	.171			
		Facility w					
		Handling Equipt.					
120	Wash Dry			1.213			
					$ .090975		
130	Inspect				.754		
	NA 397-000				$ .844975		
							$ .8449 Ea.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17097 M **ITEM NO.**

Williams Research Corporation

PART NAME Gear - ACC - 1st Reduction, and also Torque Conv. Drive

PROCESSED BY Shosh

QUANTITY/ENG. (2) Places

ENGS./YR. 1 Million

MATERIAL SAE 8640

FORM P.M.

PAGE 1 **OF** 2

SIZE 1.0 i.dia x 6.1 o.dia x .75 face x .38 web

WEIGHT 5.4 lb. @ .145 lb.

MAT. COST/Ea. $ .785

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Form- Briquette	Stokes					
	1 Man-2 Mach @ 150/Hr.		300/Hr.	.200			
20	Sinter						
30	Restrike- Coin	Press	400 Hr.	.150			
40	Heat Treat						
	Rc "C" 32-35	Holecroft Gas					
		Furnace w/					
		Quenching Tanks					
50	Magno Flux Inspect	Automatic Conveyor	400 Hr.	.150			
		w/ Tanks and Magnetizer					
		Facility					
60	Finish Bore	Excello Head					
		Boring Facility w/					
	1 Man-2 Mach @ 180 Hr.	Sizing Equipt. w/	360 Hr.	167			
		Automatic Mag. Feed					

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17097 M ITEM NO.

Williams Research Corporation

PART NAME

PROCESSED BY Shosh

QUANTITY/ENG.

ENGS./YR.

MATERIAL

FORM

PAGE 2 OF 2

SIZE

WEIGHT

MAT. COST/ENG.

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
70	Finish Broach Int.	Colonial Dbl Ram					
	Spline	Vertical w/ Locators					
		Mag Feed-Auto Eject	400/Hr.	.150			
		to Conveyor					
80	Shave	Fellows Gear					
		Shaver w/					
	1 Man-2 Mach @ 125/Hr.	Automatic Load and	250/Hr.	.240			
		Unload Facility					
90	Wash	Automatic					
100	Tuff Tride	Furnace - Tanks					
	2 hours	Quenching Facility					
110	Lap						
	1 Man-2 Mach @ 100/Hr.	Michigan Gear Lap	200/Hr.	.300			
120	Wash			1.357	$ .785		
130	Inspect				.101775		
	N/A 397-000				$ .8868		
							$ .8868

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

28163 Modified - Layout 397   2-9-72   Casting

Williams Research Corporation

ITEM NO. 28163-A

PART NAME Plate-Gear Case Cover and Accessory Mtg.

PROCESSED BY Fielek

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 2

MATERIAL Aluminum Alloy A214

FORM

5.8 lbs. @ $.312

SIZE 3/8 x 15 x 19 Approx.

WEIGHT 5.8#

MAT. COST/ENG. $1.8096

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Die Cast (w) Cavity	Automatic Die	100 Pcs/Hr	.600			
	Die 1000 Ton Mach	Casting Mach.					
20	Trim during the Cycle Time of	Trim Press		(included			
	the Above Machine			in above)			
30	Transfer to Machining						
	28163-M						
				next page			

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Layout 397

28163 - Machining
ITEM NO.

Williams Research Corporation

PART NAME Plate-Gear Case- All Mtg - Torque Converter

PROCESSED BY Shosh

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 2 OF 2

MATERIAL Al. Die Casting

FORM

SIZE

WEIGHT 5.[illegible]

MAT. COST/ENG.

OPERATION		MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Drill-Ream-c/Bore	In-Line Transfer					
	Spot Face Mtg. Holes	Set Up w/					
	Tap Oil Line Holes	Drill Plates					
	Bore Sleeve Brg. Holes	NATCO Multi-					
		Spindle Boring Equipt.					
		Hole - Bore Gage					
		Set Up / Pressure	400/Hr	.150	01125		
		Test Facility					
20	Press in Assy	Assy Transfer					
	Align Pins - Sleeve	Facility w/	400/Hr	.150	01125		
	Bearing Seals -	Bearingizer					
	Sleeve Bearings						
	Size Bearings						
				.900			
	NA 397-000				$ .0675	Labor	
					1,8096		
					$ 1.8771	Ea.	$1.8771

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17479 **ITEM NO.**

Williams Research Corporation

PART NAME Rotor - Compressor

PROCESSED BY R. H.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

MATERIAL 355-T61

FORM Casting - Perm. Mold

PAGE 1 **OF** 2

SIZE

WEIGHT 1.95 lb @ $.312 lb

MAT. COST/ENG. .6084

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Molding - spec. process						
4 men 300/hr.			.8			
Trim sprue			.2			
Heat Treat						
Preliminary Mach for Balance			.2			
Bal			.2			
Proof Spin			.2			
			1.6			
			Labor	$ .120		
				.6084 material		
				.7284		
			continued -	See P. 2		

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17479 ITEM NO.

Williams Research Corporation

PART NAME Rotor Compressor (Mach)

PROCESSED BY R. H.

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 2 OF 2

MATERIAL Alum. (17449)

FORM Cstg.

SIZE

WEIGHT

MAT. COST/ENG.

OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
Pot/Rigidax			.2			
Trace Back Side, O D and Rough Bore	Auto Tracer		.2			
Trace Front Side, Finish Bore and C'Bore	Auto Tracer		.2			
Drill			.2			
Melt Out			.2			
Clean			.2			
Deburr			.2			
Anodize				.15		
			1.4	.1050		
		Machining Cost		.2550		
		17449 Casting Cost		.7284		
			Total	$.9834		$.9834

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

30176-02

ITEM NO.

Williams Research Corporation

PART NAME Bellows -- Inner Hi-Press

PROCESSED BY H.S.

QUANTITY/ENG. 2

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL 718 Inconel

FORM Ribbon

SIZE .002 x 1" x 36

WEIGHT .05256 lb @ $7.50 lb.

MAT. COST/ENG. Ea. $ .394

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
1	Roll Form-Cut	Roll Mill					
	to 36"	Rolls					
	150' per Min	Cutoff Att.					
	9000' per Hr		3000/Hr	.020			
2	Contour Stretch	Stretch Former					
	Form and Trim	w/ Mandrel	240/Hr	.250			
	4 per Min.	Snake					
3	Butt Weld and Scarf	Butt Welder	240/Hr	.250			
	Weld	w/					
	4 per Min	Scarf Die					
				.520	.0390	Labor	
					.3940	Material	
	To Assy				.4330		
						Each	$.4330

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Layout 397 2-9-72

28041MA **ITEM NO.** Casting

Williams Research Corporation

PART NAME Housing - Gear Case - Casting

PROCESSED BY Fielek

QUANTITY/ENG. 1

ENGS./YR. 1 Million

PAGE 1 **OF** 2

MATERIAL Aluminum Alloy A214

FORM

13.2 lbs. @ .312 =

SIZE

WEIGHT 13.2 lb. @ .312

MAT. COST/ENG. $4.1184

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Die Cast (1) Cavity	Automatic Die	50/Hr	1.20			
	Die 1000 Ton Mach	Cast Machine					
20	Trim during the Cycling	Trim Press		(Incl.			
	of the above machine			in above)			
30	Transfer to Machining						
					$ .0900		
			Lbr.	1.200 Min			
						Costs on Page 2	
					Casting Only		$4.1184

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Layout 397 2-9-72

28041MB **ITEM NO.** Modified

Williams Research Corporation

PART NAME Housing - Gear Case - Machining

PROCESSED BY H.S.

QUANTITY/ENG. 1

ENGS./YR.

MATERIAL Casting Modified 17181

FORM

PAGE 2 **OF** 2

SIZE

WEIGHT

MAT. COST/ENG.

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Load Casting into	Dual Head Disc					
	Chain Conveyor	or Belt Grinder					
	Feed thru Dual	w/					
	Grinder	Positioning					
		Fixtures Attach					
	Grind Parallel	to Chain					
	and	and					
	To Dim.	w/					
		Washing Spray					
20	Drill Tap Spot Face	-in-Line-					
	c/Bore-Ream-	Transfer Mach.					
	Recess-Finish Bore	Equipt. w/ NATCO Multi					
	- Complete -	Spindle Drill Heads					
	Pressure Test Inc.	Multi Spindle Excello					
		Type Boring Heads &					
		Pressure Test Equipt.					
		Fixtures - Automatic					
	2 Men Required	480/Hr - .125 Min.					
		x 2 Men	480/Hr	.250		Mtl. $4.1184	
				1.200		Labor .1087	
			Total Labor	1.450		$4.2271	

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

I. C. 397

30099-4 ITEM NO

Williams Research Corporation

PART NAME Shoe - Low Pressure-Core Sealing

PROCESSED BY R. I. H.

QUANTITY/ENG. ______

ENGS./YR. 1 Million

MATERIAL SAE-347-430 St STL

FORM Strip

PAGE 1 OF ___

SIZE 13 GA- .094

WEIGHT 1.36 lb. @ .65 lb

MAT. COST/ENG. Ea. .884

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Blank Component						
	Parts	3 OBI Presses @					
		(30 SPM)					
	Detail A						
			1800/Hr				
	Detail B						
			3600/Hr				
	Detail C						
			1800/Hr				
				.0333			
20	Sub Assemble and	Automatic Welder	360/Hr	.1600			
	Weld 4 Joints	w					
		Shuttle Fixtures					
		and Scarf Die					
30	Coin-Knurl or Serrate	Roll Serration Die	360/Hr	.1600			
		Press					
40	Anneal - Straighten	Furnaces					
				.3533			
					$ .02649	Labor	
					.884	Material	
					.91049		
							$ .9105

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

17746 ITEM NO

Williams Research Corporation

PART NAME Oil Cooler – Alumibraze Construction

PROCESSED BY Fielek

QUANTITY/ENG 1

ENGS./YR 1 Million

PAGE 1 OF 1

MATERIAL Aluminum 3003 H-25

FORM Sheet and Tube

SIZE

WEIGHT 3.6[illegible]

MAT. COST/ENG $1.98

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Assembly Consists						
	of —						
(A)	Ten Rectangular						
	Tubes (Stamped Constr)						
(B)	(2) Round Tubes						
	(Slotted)						
(C)	(44) Sets of Fins						
(D)	Apply Alumibraze						
	Compound to the Above –						
	Assemble and Secure						
	by Spot Welding Two						
	Piece Band						
(E)	Tack Weld (4) Piece						
	Mfg. Bracket						
(F)	Dip Braze						
(G)	Transfer to Ass'y.						
			Total	6.88 Minutes Mfg. and Ass'y. of Parts.			
					$.1[illegible]		
					Total Piece Cost		$.[illegible]

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

30099-03 **ITEM NO.**

PART NAME Bellows - Outer

PROCESSED BY H. S.

QUANTITY/ENG. 2

ENGS./YR. 1 Million

MATERIAL INCO 718

FORM Ribbon

PAGE 1 **OF** 1

SIZE .002 x 1" x 57"

WEIGHT .08322 lb. ea. @ $7.50/lb.

MAT. COST/[illegible]. .625 ea.

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
1	Roll Form and cut off	Roll Mill w					
	57" length	Cut/Off attach					
	150' per Min.						
	9000' per Hr.						
			1873/Hr.	.033			
2	Contour Stretch	Stretch Former					
	Form and Trim to	w					
	Length	4 Station Mandrel					
		Snakes and					
	5 per Min.	Auto. - Trim	300/Hr	.200			
3	Butt Weld and Scarf	Butt Welder w/					
	Weld	Scarf Die	420/Hr	.143			
	7 per Min.						
				.376			
					$ .0282	Labor	
					.625	Material	
	To Assy						
					.6532		
							$ .6532 Ea.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

Williams Research Corporation

[illegible]-12 **ITEM NO**

PART NAME Bellows - Inner

PROCESSED BY H. S.

QUANTITY/ENG 2

ENGS./YR. 1 Million

PAGE 1 **OF** 1

MATERIAL INCO 718

FORM Strip

SIZE .002 x 1" x 36" - 1 Pc

WEIGHT .05256 Lb @ $7.50/Lb

MAT. COST/ENG. .394 Ea.

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
1	Roll Form and Cut	Precision Roll					
	to Length	Mill - Auto Cut Off	3000/Hr	.0200			
	150' per Min						
	3000 Hr						
2	Contour Stretch Form	Stretch Former					
	and	w					
	Trim to Length	5 Station Mandrel					
		Snakes and					
	6 per 1 Min Cycle	Auto-Trim	360/Hr	.167			
3	Butt Weld and Scarf	Butt Welder					
	Weld	w	420/Hr	.143			
	7 per Min	Scarf Die					
				.3300			
					$ .02475	Labor	
					.39400	Material	
	To Assy						
					.41875		
							$.4187 Ea.

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

30099-1 **ITEM NO.**

Williams Research Corporation

PART NAME Shoe - Base Mounting - Low Pressure

PROCESSED BY Shosh

QUANTITY/ENG.

ENGS./YR. 1 Million

MATERIAL SAE - 347 - 430 STL STL

FORM Strip

PAGE 1 **OF** 1

SIZE #13 GA (.094)

WEIGHT 1.36 Lb @ .65

MAT. COST/~~ENG~~ Ea. .884

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Stamp Component						
	Parts as Listed	Tooling from					
		30099-4 Shoe					
	Detail - A		1800/Hr				
		Note Add					
	Detail - B	Piercing Punches	3600/Hr				
		for (2) Holes					
	Detail - C		1800/Hr				
				.0333			
20	Sub Assemble and	Tooling from	360/Hr	.1600			
	Weld (4) Joints	30099-4					
	Scarf Joints						
30	Stress Anneal and						
	Straighten						
40	Belt Surface Grind	Porter Cable Wet	360/Hr	.1600			
	Mtg Face of Shoe	Belt Grinder					
	to Clean Up						
				.3533	$ .02649	Ea	
					.884		
					.91049		
							$ .9105

TABLE 2. DETAIL AND SUBASSEMBLY PROCESS SHEET (Continued)

30176-03 ITEM NO

Williams Research Corporation

PART NAME Shoe-Mounting - Hi-Pressure Seal

PROCESSED BY Shosh

QUANTITY/ENG. 2

ENGS./YR. 1 Million

MATERIAL SAE St. Stl. 347-430

FORM Strip

PAGE 1 OF 1

SIZE #13 (.094)

WEIGHT .5514 Lb @ .65 Lb

MAT. COST/~~ENG.~~ Ea. Pc. $ .3584

	OPERATION	MACHINE	MACHINE COST	LABOR (MIN)	LABOR COST	TOOL & GAGE COST	
10	Stamp and Pierce						
	Component Parts	Press w/					
	Detail A	Tooling from	1800/Hr				
		Det 30176-01					
	Detail B		3600/Hr				
	Detail C		1800/Hr				
				.0333			
20	Sub Assemble and	Butt Welder w/					
	Weld (4) Joints	Shuttle Loading					
	Mechanical	Fixtures & Cycle					
	Scarf Weld Joints	Timer Scarf Die	3600/Hr	.160			
30	Stress Anneal and						
	Straighten						
40	Belt Surface Grind	Porter Cable	360/Hr	.160			
	Mounting Base	Wet Belt Grinder					
				.3533			
					$ .02649	Labor	
					.3584	Material	
					.38489	Each	
							$ .38489

TABLE 3. MANUFACTURING COST TABULATION

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 1

PRODUCTION RATE ONE MILLION/YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL. COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
28005	HOUSING ASSEMBLY	A214 ALUMINUM			0363	.0363	1	0363
28072	STUD	1010 STEEL	1330	.02000	.00140	.02140	2	.04280
17270	PIN – DOWEL	1095–ROD STL	0075	.0011	00188	00298	4	.01192
E-10079A-8	BUSHING–SHAFT ACTUATOR	310 PM ST STL	.02	0140	.00840	.02240	1	.02240
28005-401	REGENERATOR–HOUSING–INSULATED			.5000	0345	.5345	1	.5345
28005-400	REGENERATOR–HOUSING–MACHINED–	A214 ALUMINUM	30.000	9.36	27	9.63	1	9.63
28005-900	DIE CASTING							
23006	POWER TURBINE NOZZLE ASSEMBLY				08115	08115	1	.08115
17171 REF	FLANGE–MODIFIED	REF ONLY						
E-10079A-1	FLANGE–TURBINE MOUNTING	310 STAINLESS	1.74	.9600	0075	.9675	1	.9675
E-10079A-4	CLINCH BUSHING BOLT SUPPORT	STAINLESS WIRE	0044	.0020	.00016	.00216	6	.01296
E-10079A-3	SHROUD–OUTER CASTING	HASTELLOY X	2.6331	6.1615	.03405	6.19555	1	6.19555
E-10079A-11	VANES–ADJUSTABLE	HASTELLOY X	.02	.0450	00075	.04575	17	77775
E-10079A-14	SEG-GEAR DRIVE VANE	300 PM ST STL	.04	.0280	.002	.030	17	510
E-10079A-5	SPIROL PIN	300 STAINLESS	.00018	.00013	.00128	.00141	17	02397
E-10079A-2	SHROUD–INNER CASTING	HASTELLOY X	.2901	.6500	.03625	68625	1	.68625
E-10079A-22	SCREW SHROUD ATTACH	310 ST STL	0112	.0085	00031	.00881	6	.05286

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE ______

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG
NAS1[illegible]C0[illegible]	SCREW	CORR RES WIRE	[illegible]	0018	00199	00379	2	[illegible]
[illegible]	INSULATION	INSULATION	1 LB	020	0037	00375	1	00375
[illegible]	HEAT SHIELD ASSEMBLY				.0060	.0060	1	0060
[illegible]	HEAT SHIELD RR STAMPING R BRG HSG ASSY	INCO 600	147	0423	0038	0461	1	0461
[illegible]	TAB	321 STAINLESS	0023	0019	0025	0044	4	0176
[illegible]	HEAT SHIELD FRT STAMPING R BRG HSG ASSY	INCO 600	0280	0047	0012	0059	1	0059
[illegible]	ASSY R BRG HSG & OIL SUMP				0060	0060	1	0060
[illegible]	RETAINER	HASTELLOY X	1530	990	00012	99912	1	99912
[illegible]	SLEEVE OIL SUMP ASSEMBLY	1018 TUBING	0712	1725	[illegible]	[illegible]	1	[illegible]
[illegible]	SLEEVE OIL SUMP LABYRINTH	1018 TUBING	0812	11280	0300	[illegible]	1	[illegible]
[illegible]	SLEEVE COMPRESSOR TURBINE BEARING	VJ 1000	.0730	.0421	.0750	.1171	1	.1171
[illegible]	BEARING	CEVITE COATED STL	0140	0280	1150	1430	[illegible]	17200
[illegible]	R BRG & OIL SUMP ASSY MACH				1750	1750	1	1750
[illegible]	R BRG & OIL SUMP ASSY BRAZE				.0913	.0913	1	.0913
[illegible]	HSG OIL SUMP REAR BEARING	P M IRON	3000	1170	[illegible]	1320	1	1320
[illegible]	SLEEVE BEARING SUPPORT	1030 STEEL	1420	0016	0921	0937	1	0937
[illegible]	FLANGE R BRG HSG	WASCO JET	2250	1300	086	216	1	216
[illegible]	CUP OIL SUMP	[illegible] STEEL	[illegible]	064	0027	0091	[illegible]	[illegible]
[illegible]	RING LABYRINTH SEAL	300 PM ST STL	[illegible]	0192	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	ASSY COMP TURBINE SHAFT & BRGS				[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	ASSY COMP TURB WHEEL & SHAFT				[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PRODUCTION RATE ONE MILLION/YEAR

PAGE 3

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
17559	WHEEL COMP TURBINE MACHINED	MAKE FROM 17	17		1425	1425	1	1425
23068	SHAFT COMPRESSOR TURBINE	4130 STEEL	1.2	3700	04125	41125	1	41125
17071	BEARING-SLEEVE	CLEVITE STL	020	0031	0006	0037	1	0037
17468	DAM-OIL	1030 STL	018	0017	00038	00208	1	00208
17201	DOWEL-PIN	1010 STL	003	00012	00031	00043	1	00043
17055	BEARING-SLEEVE	CLEVITE STL	0028	001	00038	00138	3	00414
17083	ASSY POWER TURBINE SHAFT BRG & SUPP				0006	0005	1	0006
17056	SUPPORT-BEARING	1020 STL	062	0868	01510	1019	1	1019
17055	BEARING-SLEEVE	CLEVITE STL	0028	001	00038	00138	1	00138
17783	BURNER & COMP TURBINE NOZZLE ASSY				.015	.015	1	.015
17782	ASSY BURNER MACHINED				0600	0600	1	0600
17780	ASSY-BURNER BRAZED	BRAZE ALLOY		0310	0750	1060	1	1060
17779	BURNER-BASIC ASSEMBLY	BRAZE ALLOY		1500	0900	2400	1	2400
17236	FLANGE-NOZZLE MOUNTING	310 STAINLESS	1 LB	750	054375	8043	1	8043
17337	FLANGE-BURNER MOUNTING	321 CENT CSTG	1.085	.6500	.0730	.7230	1	.7230
17233	SUPPORT-BURNER MTG FLANGE	310 STAINLESS	2654	2120	0300	2420	1	2420
17723	OUTER WALL BURNER	HASTELLOY X	1.3200	2.97	1050	3.075	1	3.075
17755	VANE-BURNER	HAST X SHT	0159	04	00402	04402	15	.6603
17725	INNER WALL BURNER	HASTELLOY X	822	1.8495	.0600	1.9095	1	1.9095
17235	SUPPORT	310 STAINLESS	209	1410	0225	1635	1	1635

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE [illegible]

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	HOUSING SHAFT SEAL BURNER	[illegible] PM ST STL	[illegible]	.0762	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	RETAINER AIR SUPPLY DISC	HASTELLOY X	[illegible]	.0195	.0049	[illegible]	1	.0542
[illegible]	PRIMARY PLATE	HASTELLOY X	.177	1.0687	.0521	1.1212	1	1.1212
[illegible]	NUT BURNER MOUNTING	1010 STL	.003	.0008	.0003	.0011	8	.0088
[illegible]	TAB BURNER MTG FLANGE	[illegible] ST STL	.00289	.00912	[illegible]	.02412	[illegible]	.14472
[illegible]	LOCK RING	321 STAINLESS	.0319	.0190	.0110	.0300	1	.0300
[illegible]	SEALS LABYRINTH	INCO [illegible]	.0061	.0011	.0017	.002	[illegible]	.049
[illegible]199	SPACER	304 STAINLESS	[illegible]	.0132	.0060	.0192	4	.0768
[illegible]	SPACER	304 STAINLESS	.0047	.004	.0006	.0046	2	.0092
[illegible]	ASSEMBLY HEAT SHIELD				.0099	.0099	1	.0099
[illegible]	FLANGE TAB SUPPORT	INCO	.000613	.00128	.000112	.00139	1	.00139
[illegible]	HEAT SHIELD	321 STAINLESS	[illegible]	.0211	.0013	[illegible]	1	[illegible]
MS[illegible]	SCREW	CORR RES WIRE	.0027	.00054	.00009	.00063	6	.00378
[illegible]128	NOZZLE RING-MACHINED				.0525	.0525		.0525
E-10079-B	OIL DRAIN TUBE ASSY REAR BEARING				.00375	.00375	1	.00375
E-10079B-[illegible]	TUBE OIL DRAIN REAR BEARING	[illegible] ST TUBE	[illegible]	.0128	[illegible]	.01621	1	.01655
E-10079B	BELLOWS OIL DRAIN TUBE REAR BEARING	[illegible] ST TUBE	[illegible]	.00385	.00075	[illegible]	1	.00460
E-10079B-[illegible]	FLARED CONNECTOR OIL DRAIN TUBE	[illegible] ST TUBE	[illegible]	.0060	[illegible]	.01122	1	.01122
E-10079B-1	MALE ELBOW REAR OIL DRAIN	BRASS	[illegible] LB	.1955	[illegible]	[illegible]	1	[illegible]
E-[illegible]B-[illegible]	GASKET REAR BEARING OIL DRAIN	COPPER&ASBESTOS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 5

PRODUCTION RATE ONE MILLION/YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
E-10079A-[illegible]	GEAR RING - VANE DRIVE	310 ST PM	804	5628	014625	577425	1	577425
E-10079A-10	FINGERS	310 STAINLESS	0479	03353	00038	03391	3	10173
E-10079A-6	BOLT FINGER	300 STAINLESS	011	008	00016	00816	6	.04896
E-10079A	WASHER LOCATING FINGER	300 STAINLESS	.0056	.0039	.00037	.00427	3	.01281
E-10079A-16	COUPLING	300 STAINLESS	018	0125	00437	01687	1	01687
E-10079A-13	SHAFT ACTUATOR	305 STAINLESS	035	0175	00287	02037	1	02037
E-10079A-17	WASHER THRUST	300 STAINLESS	0045	0033	00005	00335	1	00335
E-10079A-9	SPIROL PIN	300 STAINLESS	00096	00067	00128	00195	2	0039
E-10079A-12	ACTUATOR ARM	HRS 1010	0227	0045	00205	00655	1	00655
23045	SLEEVE & FUEL SLINGER ASSEMBLY				0600	0600	1	0600
17549	SLEEVE COMPRESSOR TURB SHAFT	17-4 PH	1.93	1.602	.0750	1.677	1	1.677
17790	SLINGER FUEL	17-4 PH	2803	1766	0508	2274	1	2274
23044	DIFFUSER HEATSHIELD & BURNER CVR				.0300	.0300	1	.0300
17623	COVER ASSEMBLY-BURNER	BRAZE ALLOY	0017	0068	0300	0368	1	0368
17643	FLANGE BURNER COVER	321 ST STL	40	.30	.016875	.316875	1	.316875
17618	BURNER COVER 28233 REF	HASTELLOY X	605	1.361	0375	1.3985	1	1.3985
23083	STUD	864D STL	0208	00249	000045	002535	1	002535
MS21[illegible]	SCREW	COR RES STL AP	0023	0012	000562	001762	6	010572

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PRODUCTION RATE ONE MILLION YEAR

PAGE

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	BURNER & DIFFUSER HEATSHIELD ASSY				[illegible]	[illegible]	1	[illegible]
[illegible]	HEAT SHIELD DIFFUSER BURNER	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	RING, BURNER & DIFF HEAT SHIELD SUPPORT	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
[illegible]	TAB	321 STAINLESS	[illegible]	.0019	[illegible]	[illegible]		[illegible]
[illegible]	FLANGE	[illegible] STL	LBS	[illegible]	[illegible]	[illegible]	1	[illegible]
[illegible]	DIFFUSER & FUEL DISTRIBUTOR MANIFOLD ASSY				.0600	.0600	1	.0600
[illegible]	FUEL MANIFOLD ASSY				.0600	.0600	1	.0600
[illegible]	MANIFOLD, FUEL DISTRIBUTOR MANIFOLD	316 SS PM	.868	1.33	.0750	1.4050	1	1.4050
[illegible]	PIN, FUEL DISTRIBUTOR MANIFOLD	[illegible] STL	.0013	.000398	.0045	.004898	[illegible]	.014694
[illegible]	SLEEVE	316 STL	.001	.00091	.0045	.00541	1	.00541
[illegible]	FUEL MANIFOLD ASSY				.030	.030	1	.030
[illegible]	SLEEVE, FUEL MANIFOLD	316 STAINLESS	[illegible]	.3002	[illegible]	[illegible]	1	.3637
[illegible]	FUEL MANIFOLD ASSY MACH				.060	.060	1	.060
[illegible]	DIFFUSER DIE CASTING	A.13 ALUM	[illegible]	1.5625	.25	1.8125	1	1.8125
[illegible]	PLUG	316 STAINLESS	.00042	.000147	.000075	.000222		.000444
[illegible]	O RING			.00283		.00283	1	.00283
[illegible]	PIN PLUG	316 STAINLESS	.0023	.0008	.0075	.0083	1	.0083
[illegible]	O RING			.00283		.00283	1	.00283
AN-[illegible]	BOLT	1018 STL	.007	.0014	.00012	.00152	4	.00608
[illegible]	O RING			.01128		.01128	1	.01128

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 7

PRODUCTION RATE ONE MILLION/YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
MS 9320-10	WASHER	1010 STL	0047	00047	.00001	.00048	4	.00192
17480	IMPELLER COMPRESSOR ROTOR ASSY				075	.075	1	.075
17479	ROTOR COMPRESSOR (MACH	355–T61 AL			255	.255	1	.255
17449	ROTOR COMPRESSOR	355–T61 AL	1 95	.6084	.120	.7284	1	.7284
17201	DOWEL PIN	1010 STL	.003	00012	00031	00043	1	00043
17569	SLEEVE–IMPELL RIVE	4130 STL	261	0600	0525	.1125	1	1125
17054	LOCKWASHER	1010 STL	.0269	0024	.0015	.0039	1	0039
17053	NUT	4140 STL	.0551	0275	01875	04625	1	.04625
17052	WASHER–THRUST	SAE–1060	.07	.007	0281	0351	1	.0351
17040	BEARING–FRONT MAIN	ALUM PM	3750	05	.0495	0995	1	0995
17404	RING RETAINING (TRO ARC)	SAE–1075	093	0085	00016	00866	1	00866
17302	KEY	W–Z STL	.00259	.00023	.0076	.00783	2	.01566
17050–M	GEAR ACC DRIVE INPUT PINION	SAE 8640	1.2	.174	090	2643	1	2643
17048	WASHER	1010 STL	.019	0020	00027	.00227	1	00227
17047	NUT	1113 STL	12	0192	00375	.02295	1	02295
17578	POWER TURBINE & SHAFT ASSY				072525	.072525		072525
17036	CUP–WASHER	321 ST STL	0141	0075	0045	0120	1	0120
17295	NUT	1010 STL	019	0038	00084	00464	1	.00464

TABLE 5. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
[illegible]

DIRECT MANUFACTURING COST ESTIMATE AUTOMOTIVE GAS TURBINE ENGINE

PAGE

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	[illegible]	MATERIAL COST	[illegible]	[illegible] COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]
[illegible]	ASSEMBLY [illegible] TURBINE SHAFT				[illegible]	[illegible]		[illegible]
	CROSS TUBE	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	END [illegible] POWER TURBINE SHAFT	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	END POWER TURBINE SHAFT	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]
[illegible]	SHELL POWER TURBINE MACH				[illegible]	[illegible]		[illegible]
[illegible]	WASHER POWER PINION DRILL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	PINION POWER OUT REDUCTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	KEY	[illegible] ALLOY STL	[illegible]					[illegible]
[illegible]	LOCKWASHER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	NUT	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]
[illegible]	OIL COOLER ALUMINUM [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	MACHINING				[illegible]	[illegible]		[illegible]
[illegible]	PLATE GEAR CAST ACC MTG CASTING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	ASSEMBLY OIL FILTER HSG				[illegible]	[illegible]		[illegible]
[illegible]	HSG OIL FILTER CASTING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	NIPPLE OIL FILTER	SAE [illegible] STL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
AN [illegible]	STUD	[illegible] ALLOY STL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	VALVE	[illegible] STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	SPRING	STEEL MUSIC WIRE	[illegible]		[illegible]	[illegible]		[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE PAGE [illegible]

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	PLUG	ALUM BAR [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20014-1	O-RING			.00925		.00925	1	.00925
17343	RING	1020 STEEL	[illegible]	.0018	[illegible]	.0019	1	.0019
17344	PLUG	2011 ALUM	.004	.0018	.00028	.00208	1	.00208
MS 21900D-16	UNION	1020 STEEL	.29	.0435	.0016	.0451	1	.0451
MS 9120-10	WASHER	1020 STEEL	.0047	.0047	.00048	.00518	2	.010360
AN 501128	SCREW	4130	[illegible]	.0044	.0045	.0089	1	.0089
17357-M	NUT	1020 STEEL	.018	.0016	[illegible]	.00227	1	.00227
197-[illegible]	OIL PUMP BOD	A.?13 ALUM DIE CST		[illegible]	[illegible]	.2050	1	.2050
23165	GEROTOR PUMP	PM [illegible] STL	[illegible]	.1178	[illegible]	.1478	1	.1478
MS 16997-60	SCREW	4130 STL	.142	.0029	.00015	.00305	4	.0122
MS 9120-10	WASHER	1020 STL	.0047	.0028	[illegible]	.00305	4	.0122
197-[illegible]	SHAFT ACCESSORY WORM DRIVE GEAR	SAE 8620 STL	[illegible]	[illegible]	[illegible]	.2663	[illegible]	.2663
197-[illegible]	OIL SUCTION TUBE ASSEMBLY				[illegible]	.0124		.0124
197-[illegible]	TUBE	C.R. STEEL	[illegible]	.0042	[illegible]	[illegible]	1	[illegible]
197-[illegible]	CUP	H.R. STEEL	.00144	[illegible]	[illegible]	.0038		.0038
197-[illegible]	SCREEN	300 ST STL	.004	[illegible]	[illegible]	.01470	1	.01470
[illegible]	O-RING			.0094		.0094		.0094
[illegible]	SLEEVE BEARING	P.M.	[illegible]	.0156	[illegible]	[illegible]	1	[illegible]
[illegible]-M	SHAFT SEAL	FELT C.R.S.	[illegible]	[illegible]	[illegible]	[illegible]		.0057
[illegible]	DOWEL	[illegible] ALLOY STL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN [illegible]

DIRECT MANUFACTURING COST ESTIMATE AUTOMOTIVE GAS TURBINE ENGINE PAGE

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL [illegible]	[illegible]	[illegible] COST	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	GEAR ACC DRIVE TORQUE CONVERTER	SAE [illegible]		[illegible]				[illegible]
[illegible]	GEAR ACC 1ST REDUCT (TORQUE CONV DRIVE)	SAE [illegible]		[illegible]		[illegible]		[illegible]
[illegible]	GEAR 1ST RED POWER TRAIN	SAE [illegible]		[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	SPACER GEAR ACC IDLER	P.M. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	SHAFT IDLER ACC GEAR	SAE [illegible]		[illegible]				[illegible]
[illegible]	THRUST WASHER	[illegible] STEEL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	GEAR ACC DRIVE PINION	SAE [illegible]		[illegible]	[illegible]			[illegible]
[illegible]	SHAFT IDLER POWER DRIVE	SAE [illegible]	[illegible]	[illegible]		[illegible]		[illegible]
[illegible]	GEAR SMALL STARTER SET	P.M. [illegible]		[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	THRUST WASHER	[illegible] STEEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	WORM SHAFT ASSY OIL PUMP DRIVE				[illegible]	[illegible]		[illegible]
[illegible]	SHAFT PUMP DRIVE	[illegible] STEEL		[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	GEAR WORM	P.M. BRONZE		[illegible]		[illegible]		[illegible]
[illegible]	DOWEL PIN	[illegible] STL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	GEAR ACC DRIVE	SAE [illegible]		[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	DOWEL PIN	[illegible] STEEL	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	GEAR POWER DRIVE PINION	[illegible] STEEL		[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	GASKET LIQUID PLASTIC						[illegible]	
[illegible]	HOUSING GEAR CASE CASTING	ALUM ALLOY	[illegible]	[illegible]		[illegible]		[illegible]
[illegible]	GEAR CASE MACH							
[illegible]	GEAR CASE SUB ASSY				[illegible]			[illegible]
								[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 11

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	OIL SUPPLY LINE ASSY				[illegible]	[illegible]	1	[illegible]
[illegible]	TUBE OIL LINE	BUNDY TUBE	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	NUT FLARE	[illegible] STEEL	.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CONNECTOR	[illegible] STEEL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	DIP STICK ASSY	[illegible] STEEL	[illegible]	[illegible]	[illegible]	.4173	[illegible]	.4173
17201	ROLL PIN	[illegible] STEEL	[illegible]	.00012	.00031	.00041	[illegible]	.00144
28009	SPROCKET SMALL	4620 STL PM	[illegible]	.36	[illegible]	[illegible]	[illegible]	.495
17270	DOWEL PINS	4130 STEEL	[illegible]	.0036	[illegible]	.00444	[illegible]	.02664
17285	SEAL ALTERNATOR DRIVE SHAFT	FELT C R S	[illegible]	.0054	[illegible]	.0091	[illegible]	.0182
17371-M	SLEEVE BEARING IRON COPPER	P M	[illegible]	.00159	.00223	.00382	5	.01910
17377-M	PLUGS	2011 ALUM	.004	.0018	.00030	.00210	[illegible]	.00420
20012-M	GASKET LIQUID PLASTIC						AS REQ'D	
AN-93202	PLUG 1/8 PIPE	SAE 1040 STL	[illegible]	.0056	[illegible]	[illegible]	4	.023148
MS-9320-10	WASHER	1010 STL	.004	.00047	[illegible]	.00048	1	.00048
MS-35338-44	LOCKWASHER 1/4	1020 CARB STL	.0018	.00038	.00001	.00039	10	.00390
AN-101129	SCREW	4130 STEEL	.0142	.0044	.0045	.0089	1	.0089
28037	COVER TURBINE AIR INLET	A214 AL DIE CAST	1.45	.4350	.04875	.48375	1	.48375
17270	DOWEL PINS	4130 STL	.009	.0036	.00084	.00444	2	.00888

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 12

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
[illegible]	GEAR CASE ASSY 3002 REF				1499	1499	1	1499
[illegible]	PULLEY ALTERNATOR	H.R.S.	1.38	[illegible]	[illegible]	[illegible]	1	[illegible]
E-[illegible]	BOLT [illegible] 2804 REF	[illegible] STL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
~~E-[illegible]~~	LOCKWASHER 2804 REF	[illegible] CARB STL	[illegible]	[illegible]	[illegible]	00081	1	00081
E-[illegible]	EXHAUST DIFFUSER ASSEMBLY 28079 REF				1451	1451	1	1451
28076	VANE OUTER	321 STAINLESS	[illegible]	2062	[illegible]	44524		44524
~~28077~~	~~SUPPORT~~	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
28078	VANE DIVIDER	321 STAINLESS	[illegible]	1175	[illegible]	1640	1	1640
17754	CAP	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
28077	VANE INNER	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
MS 9xxx-[illegible]	BOLTS HI TEMP	321 STAINLESS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17759	PLUG IGNITER			1.30		1.30	1	1.30
30176	SEAL ASSY HIGH PRESSURE				[illegible]	[illegible]	[illegible]	[illegible]
30176-1	SHOE CORE SEALING HIGH PRESS	SAE 347 ALT 430SS	3514	[illegible]	[illegible]	18489	[illegible]	[illegible]
30176-2	BELLOWS INNER HIGH PRESS	718 INCO	3525	144	[illegible]	4330	[illegible]	8660
30176-3	SHOE MOUNTING HIGH PRESS SEAL	347 SS	3514	[illegible]	[illegible]	18489	2	[illegible]

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

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PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
28051	RETAINER-HIGH PRESSURE SEAL	121 STAINLESS	.0037	.0028	.00283	.00563	2	.01126
28052	RETAINER-HIGH PRESSURE SEAL	121 STAINLESS	.0037	.0028	.00283	.00563	2	.01126
MS24676-6	SCREW 6-32 X 1/4	100 STAINLESS	.0073	.00046	.0001	.00056	12	.00672
30099	LOW PRESSURE SEAL ASSY				.06765	.06765	4	.2706
30099-1	SHOE-BASE MTG-LOW PRESSURE	100 STAINLESS	1.36 LB	.2840	.02649	.3105	4	1.2420
30099-2	BELLOWS-INNER	INCO 718	.05256	.394	.0247	.4187	4	1.6748
30099-3	BELLOWS-OUTER	INCO 718	.08322	.625	.0282	.6532	4	2.6128
30099-4	SHOE-LOW PRESS CORE SEALING	347-430 SS	1.36	.284	.02649	.31049	4	1.24196
28065	RETAINER-LOW PRESSURE SEAL	121 STAINLESS	.0080	.006	.0283	.0343	2	.0686
28066	RETAINER-LOW PRESSURE SEAL	121 STAINLESS	.0080	.006	.0283	.0343	2	.0686
MS24676-6	SCREW 6-32 X 1/4	100 STAINLESS	.0073	.00046	.0001	.00056	24	.01344
28029 LH	CORE DRIVE COUPLING ASSY				.01125	.01125	1	.01125
17036	SPRING CORE DRIVE	VASCO JET	.268	.0390	.0075	.0465	6	.2790
17035	CORE DRIVE COUPLING	1010 STEEL	.0368	.0033	.00375	.00705	2	.014100
28028	STOP WASHER-CORE DRIVE	1010 STEEL	.131	.01179	.0012	.01299	2	.02598
28234 RH	CORE DRIVE COUPLING ASSY				.01125	.01125	1	.01125
28006-A	CORE COVER ASSEMBLY LH				.07905	.07905	1	.07905
28006-1	STIFFENER	1020 STEEL	.682	.061	.00375	.06475	1	.06475

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE AUTOMOTIVE GAS TURBINE ENGINE PAGE [illegible]

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG
[illegible]	BEARING HOUSING	SAE [illegible] TUBG	[illegible] LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	BOLT REINFORCEMENT	H R S	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	SEAL SHELF	[illegible] STAINLESS	[illegible] LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CORE COVER STMPG [illegible] DUCT LH	SAE [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	INTAKE SEPARATOR PLATE	SAE [illegible]	[illegible] LB	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	BEARING SLEEVE	IRON COPPER MAT	[illegible] LB	[illegible]	[illegible]	[illegible]	[illegible]	.0515
[illegible]	SHAFT SEAL	FELT & CRS	[illegible]	.0054	.0037	.0091	[illegible]	[illegible]
[illegible]	SHOE ASSY CORE RETAINING LH	310 SS PM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1945
MS [illegible]	COTTER PIN		.00015	.00009	[illegible]	[illegible]		.00043
[illegible]	GUIDE CORE RETAINING SPRING	304 STAIN PM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	SPRING	302 STAIN WIRE	.0097	.0043	[illegible]	.00589	[illegible]	[illegible]
[illegible]	SCREW	4130 STL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.008387
MS [illegible]	JAM NUT	4130 STL	[illegible]	.0042	[illegible]	[illegible]	[illegible]	.004815
[illegible]	SHOE CARBON	GRAPHITE	.0099	[illegible]	[illegible]	[illegible]		.00734
[illegible]	GASKET LIQUID PLASTIC							

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PRODUCTION RATE ONE MILLION/YEAR

PAGE [illegible]

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
MS1699[illegible]	BOLT	4130 STL	0142	0029	00015	00305	[illegible]	07930
MS9320-[illegible]	WASHER FLAT	1040 STL	0047	00047	[illegible]	00048	[illegible]	017493
MS35338-44	WASHER LOCK	1095 STL	0018	00018	0001275	0005675	[illegible]	0131250
20012	GASKET LIQUID PLASTIC							
28006-[illegible]	STIFFENER	1020 STL	341	061	00375	06475	1	06475
28006-[illegible]	BEARING HOUSING	SAE 1020 TUBING	338 LB	[illegible]	[illegible]	11325	1	11325
28006-[illegible]	BOLT REINFORCEMENT	H.T.S.	166 LB	243	[illegible]	1860	[illegible]	17200
28006-[illegible]	SEAL SHELF ALLOY	8 CHROME	1.488 LB	179	0369	2159	1	2159
28006-B	CORE COVER ASSY RH				07905	07905	1	07905
28006-1B	CORE COVER STAMPING W/ DUCT RH	SAE-1040	15.00	165	037	202	1	202
28006-[illegible]	INTAKE SEPARATOR PLATE	SAE-1040	2.28 LB	205	0075	2125	1	2125
28111	SPROCKET IDLER	PM 4620	164 LB	026	0130	039	1	039
28006-[illegible]	BEARING SLEEVE	IRON-COP MATRIX	166 LB	050	0015	0515	1	0515
17291	SHAFT SEAL	FELT & CRS	.0048 .0137	0054	0037	0091	3	0273
28097	SHOE ASSY CORE RETAINING RH INST	410 SS-PM	0572	072	0225	0945	1	0945
28115	BOLT-LOAD IDLER SPROCKET	SAE-1060	06	0558	0169	0727	1	0727
MS24665-[illegible]	COTTER PIN		00015	00009	000125	000215	2	00043
28101	GUIDE CORE RETAINING SPRING	304 STAIN PM	09625	04325	00825	05150	1	05150
28102	SPRING	300 STAIN WIRE	0097	0043	0212	0255	1	0255
28103	SCREW	4130 ALLOY STL	082	0082	000187	008387	1	008387
MS24400-5	JAM NUT	1035 CARBON STL	03	0045	000315	004815	1	004815

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE AUTOMOTIVE GAS TURBINE ENGINE

PAGE [illegible]

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG
[illegible]	CHAIN REGENERATOR DRIVE	CHAIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CHAIN GUARD STAMPING	[illegible] STL	[illegible]	[illegible]	.0150	.18103	[illegible]	.1810
[illegible]	EXHAUST DIFFUSER COVER INSTL	LINE INSTALLATION						
[illegible]	INSULATION	INSULATION	[illegible] LB	[illegible]	.0038	.1238		.1238
[illegible]	PLATE EXH DIFFUSER	CRS	[illegible]	.1458	.0075	.1533	1	.1533
8031	DOUBLER EX DIFFUSER	HRS	1.338	.0934	.0208	.1142	[illegible]	.1142
[illegible]	GASKET HOUSING EX DIFFUSER	PM A-[illegible]	.078	.092	.005	.097	[illegible]	.097
[illegible]	PANEL EX DIFFUSER	HRS	1.596	.13	.012	.142	1	.142
E-[illegible]	CORE DRIVE ASSY 8011 REF				.0445	.0445	[illegible]	.0890
MS9060-[illegible]	BOLT	410 STAINLESS	.0112	.0085	.000173	.008873	[illegible]	[illegible]
[illegible]	SLEEVE	4130 STEEL	.37	.1425	.0075	.1500	[illegible]	.3000
[illegible]	SHAFT CROSS CORE DRIVE	REFERENCE ONLY SEE E 10082 -						
8023	SPROCKET	1040 STEEL	.378	.0792	.0075	.0867	2	.1734
MS9[illegible]-10	WASHER	1010 STEEL	.0036	.00036	.00061	[illegible]	[illegible]	.00814
[illegible]	SHOULDER BOLT	4140 STEEL	.1523	.023	.0300	.0530	[illegible]	.1060
E-10082	CROSS SHAFT 8004 REF				.0375		1	.0375
8009	SPROCKET	1035 PM STL	.114	.018	.0135	.0315	[illegible]	.0630
8010	SPROCKET CORE DRIVE	1040 STEEL	.336	.084	.0112	.0952	[illegible]	.0952
E-10082-[illegible]	CROSS SHAFT	SAE 1040 STL	1.3 LB	.190	.00687	.19687	[illegible]	.19687
E-10082-1	BOLT	4130 STEEL	.111	.0106	.0001	.0107	[illegible]	.0214
E-10082	LOCKWASHER	1035 CARBON STL	.0045	.0003	.0001	.0004	[illegible]	.0016

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE MICHIGAN USA

DIRECT MANUFACTURING COST ESTIMATE – AUTOMOTIVE GAS TURBINE ENGINE

PAGE 17

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
E-10082-1	SPACER-CROSS SHAFT	1020 CARB STL	051 LB	0047	0003	0050	[illegible]	0100
28104-[illegible]	CHAIN GUARD STAMPING	1010 STEEL	1188	0132	00873	02193	1	02193
28108-1	CHAIN GUARD STAMPING	1010 STEEL	1287	02958	00863	03821	1	03821
MS16997-40	BOLT	4130 STEEL	0142	0029	00015	00305	8	02440
MS35338-44	WASHER-LOCK	1080 STEEL	0018	00038	0001275	0005075	8	00406
28001	FINAL ENGINE ASSEMBLY					1.40		5.40
17127-17559	COMP-TURBINE WHEEL CASTING 19.50 OEM	INCO 713 LC	2.71			17.4928	1	17.4928
17126-17328	NOZZLE RING-CASTING 11.00 OEM FACTORED	INCO 713 LC	1.168			9.430	1	9.430
17179-17562	PWR TURBINE WHL CASTING 42.75 OEM	INCO 713 LC	2.73			18.8253	1	18.8253
17021	CORE-HEAT EXCHANGER	CERCOR	22.00			9.02	2	18.04
	FUEL CONTROL					38.00	1	38.00

TABLE 3. MANUFACTURING COST TABULATION (Continued)

Williams Research Corporation
WALLED LAKE, MICHIGAN, USA

DIRECT MANUFACTURING COST ESTIMATE - AUTOMOTIVE GAS TURBINE ENGINE

PAGE [illegible]

PRODUCTION RATE ONE MILLION YEAR

PART NUMBER	PART NAME	MATERIAL	WEIGHT	MATERIAL COST EACH	LABOR COST EACH	LABOR & MTRL COST EACH	QUANTITY PER UNIT	TOTAL COST PER ENG.
	EXHAUST SYSTEM							
[illegible]	TRANSITION EXHAUST DUCT	[illegible] ALUM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	EXHAUST DUCT R.H.	[illegible] ALUM	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
[illegible]	EXHAUST DUCT L.H.	[illegible] ALUM	[illegible]	[illegible]	[illegible]	[illegible]		
	ASSY HANGER STRAPS TO EXHAUST DUCT	[illegible] ALUM			[illegible]	[illegible]	1	[illegible]
	STRAP EXHAUST DUCT BOTTOM	[illegible] ALUM	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]
	STRAP EXHAUST DUCT TOP	[illegible] ALUM	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]

stations and the length of the assembly line required is a function of the work content and the units per hour required. Application of this logic to the turbine engine assembly requirements produced the following data:

a. Assembly time - 1.2 hrs.

b. Number of assembly operations - 40

c. Length of assembly line (assuming 4 ft. work stations) - 400 ft.

d. Number of men required to produce 300 units per hour - 360

The labor content for each of these assembly operations was also included on the tabulation sheets. Once the preliminary tabulation sheets were complete, they were reviewed to again segregate the high cost items for additional value analysis before finalizing the part cost. The high alloy and stainless steel parts were listed and their strategic metal content determined and tabulated in order to make available the total weight of each critical element in the engine.

MASS PRODUCTION MANUFACTURING PROCESSES

The basic mass production machining and fabrication techniques and processes currently in use in the automotive industry can be used to produce nearly all of the components for the automotive turbine engine. For high volume manufacturing of turbine engine parts, new handling, loading, unloading, and transfer equipment will be required; however, there is nothing significantly unique about turbine engine components that would prevent the machine tool industry from designing and building this equipment in approximately the same time frame as that required to produce similar equipment for piston engine parts. This time frame is estimated to be not more than 18 months from the beginning of design to the start of production in the user's plant.

The exceptions to the use of current processes and techniques are in the mass production of ceramic regenerator cores, fuel control units, and investment castings (or an alternate turbine wheel production process). These exceptions became obvious after a review of the vendor quoted prices for these items, which show an unreasonable proportion of labor cost to material cost. An additional area of concern, though of somewhat lesser magnitude, is the cost of high alloy sheet metal parts in the burner components. To ensure that a completely acceptable turbine engine cost can be attained by 1975, process development in these areas is obviously necessary; however, the development of these processes by 1975 is considered to be well within the state of the art for the industry.

Ceramic Regenerator Cores

The ceramic regenerator cores utilize silica as the basic ingredient. Silica is obviously abundant and even in a high purity fused form should not cost more than $.17 per pound. The properties of silicon nitride also appear feasible for this application, and the cost of silicon powder is approximately $.26 per pound. Because the cores for the engine weigh approximately 11 pounds each, a raw material cost of $2.00 to $3.00 per core is indicated. Mass production processing would most likely be continuous, i.e. dry powder mixed with an organic binder and extruded into rod form, calendered, corrugated, wound on a core, oven cured, and then machined. For this type of processing, the usual 80/20 material/labor relationship should exist. Allowing 380% overhead and a mark-up of 30% to cover general and administrative costs and profit, a selling price of approximately $9.00 each is obtained.

Investment Castings

The engine incorporates four investment castings. The vendor quoted prices for 1,000,000 castings per year and the casting weights are:

a.	Aluminum Compressor Rotor	$13.50	2.0 lbs.
b.	Compressor Turbine Nozzle (713LC)	$23.00	1.2 lbs.
c.	Compressor Turbine Wheel (713LC)	$39.50	2.7 lbs.
d.	Power Turbine Wheel (713LC)	$42.75	2.7 lbs.

It is believed that the aluminum compressor rotor can be developed as a permanent mold centrifugal casting; and as such, could be produced for approximately $.74 direct cost. After adding G & A and profit, the selling price would be approximately $1.80 each.

The compressor turbine nozzle is made from a super alloy material (713 LC); comprised of 75% Nickel, 4.5% Molybdenum, 12% Chromium, 6% Aluminum and small amounts of Cb, Ti, B and Zr. The raw material cost would be approximately $1.50 per pound; and although it must be vacuum melted, the metal cost at the spout should not exceed $2.00 per pound. The nozzle weighs 1.2 pounds; and if the sprue is assumed to be 50% or 0.6 pounds, the poured weight is then 1.8 pounds worth $3.60 (at $2.00 per lb.). If a sprue return credit of 50% of the original value or $1.00 per pound is now allowed, the final material cost becomes $3.00 per casting. Conventional foundry casting techniques, wherein the material/labor ratio is 80/20, would generate a direct cost of approximately $3.75, which in turn would provide a selling price of approximately $8.00 per casting after adding the 380% overhead and the 30% profit. The same rational applied to the turbine wheels would result in a selling price of approximately $14.00 each.

The investment or lost wax casting process currently in use apparently is not readily adaptable to the high volume, low cost techniques of the automotive foundries. The process is complicated, requires an excessive amount of time, and utilizes expensive materials that at the present time are generally not recoverable. However, the process has much to offer the gas turbine industry, i.e. excellent surface finish, dimensional control of sophisticated shapes, and in some instances the only method of casting some shapes.

New, faster drying precoats are needed along with faster drying refractory shell coating combinations. Completely automated handling equipment will naturally be developed, and the recovery and reprocessing of refractories may offer additional possibilities for cost reduction. Casting yield might also be increased by the incorporation of centrifugal casting techniques.

Several alternate casting concepts exist for turbine wheel and nozzle production. Additional development in these areas is desirable in order to determine the feasibility of the processes and to indicate which alternative offers the greater producibility.

Electronic Fuel Control

While the vendor quoted price for the electronic fuel control unit ($94.00 per unit) seems to be high in view of the high production rate, it is anticipated that time and the application of value analysis techniques will reduce this price by at least 20% by 1975.

High Alloy Sheet Metal

The cost of high temperature, high alloy sheet metal for the fabrication of burner components constitutes a lesser, but significant cost problem. The projected cost of converting $1.30 per pound ingot to sheet metal for an additional $1.00 per pound does not seem unreasonable until compared with the cost of converting mild carbon steel, or even stainless steel, from ingot to sheet; in which case, the anticipated selling price would be approximately $1.50 per pound. The consideration of more abundant, less expensive ceramic materials could result in a substantial cost savings for the burner components.

COMPARISON WITH OTTO CYCLE ENGINE

Manufacturing Costs

In order to attempt a manufacturing cost comparison between a current piston engine and the conceptual automotive turbine engine, it was first necessary to obtain a [illegible] price for the piston engine at a known level of assembly (with or without accessories, etc.). Numerous indirect sources were solicited for this estimate, and the results were solicited for this estimate, and the results were averaged to obtain a price of $292.50 for a small V-8 piston engine at the transfer level. The Transfer Price is defined as that price charged by the engine manufacturer as the engine is moved to the vehicle assembly plant. The engine is assumed to be a bare engine and does not include the fuel pump, spark plugs, coil, distributor, air cleaner, carburetor, starter, or alternator.

The Transfer Price of $292.50 is also assumed to include 380% overhead and a 15% mark up for profit and general and administrative costs. Therefore, to obtain the direct cost of the piston engine:

$$\text{Transfer Price} = 1.15\ (\text{Material} + \text{Labor} + 3.8\ \text{Labor})$$

Also:

$$\text{Labor/Material} :: 20/80$$

Or:

$$4.0\ \text{Labor} = \text{Material Cost}$$

Then:

$$\text{Transfer Price} = 1.15\ (8.8\ \text{Labor})$$

Or:

$$\text{Transfer Price} = 10.12 \times \text{Labor}$$

For the quoted piston engine:

$$\text{Labor Cost} = \frac{\$292.50}{10.12} = \$\ 28.80$$

$$\text{Material Cost @ 4 X Labor} = \underline{\$115.20}$$

$$\text{Total Direct Cost} = \$144.00$$

To present a complete piston engine that would be functionally comparable with the turbine engine analyzed, it was then necessary to add the fuel pump, spark plugs, coil, etc., and all engine related accessories (see Table 4). Again, numerous sources were solicited for these prices, which were also factored for direct cost content. The automotive turbine engine direct manufacturing cost is shown in the second column. Certain items comprising the turbine engine have

TABLE 4. ESTIMATED MANUFACTURING COSTS FOR A V-8 PISTON ENGINE, AND AN AUTOMOTIVE TURBINE ENGINE

Note: All prices quoted are direct cost (labor and material only).

	V-8 Piston Engine	Automotive Turbine	
		Current Pricing & Processing	Target Pricing & Developed Processing
Base Engine			
Turbine Wheels		$ 36.31	$ 14.19
Turbine Nozzle		9.43	3.25
Regenerators		18.04	7.40
Remaining Parts		87.48	87.48
Total Base Engine	$144.06	$151.26	$112.32
Fuel System	5.85	38.00	30.00
Ignition System (Including Spk Plgs)	5.13	2.82	2.82
Air Cleaner & Intake	1.54	3.08	3.08
Cooling System	11.93	-	-
Exhaust System	4.90	10.10	10.10
Starter	4.10	4.10	4.10
Battery	3.89	5.14	5.14
Alternator	5.30	5.30	5.30
Total	$186.64	$219.80	$172.86

been segregated to allow a direct cost comparison of functionally comparable parts. As presented, the direct manufacturing cost of a small V-8 piston engine is $186.64, while the direct cost of the automotive turbine engine is $219.80.

A third column is included on the table and presents the 1975 target prices for the automotive turbine engine. The "high cost" components have been segregated to allow a direct comparison of the target cost with the present vendor quoted prices (factored for direct cost) for 1,000,000 units per year. The target prices shown for the electronic fuel control, ceramic regenerator cores, turbine wheels and turbine nozzle are based on the projected mass production manufacturing processes previously discussed in this report. These target prices are considered to be more realistic because the manufacturing processes discussed are well within the scope of process development by 1975. As can be seen, the turbine engine with components at the target price level represents a cost advantage over the present piston engine. The addition of the required emission control equipment to make the present piston engine comply with the 1976 Federal Emissions Standards would increase the cost advantage for the automotive turbine engine. This equipment has been projected to have a direct cost from $40.00 to $115.00. The assumption is made that no increase in cost will occur with regard to gas turbine combustion systems in reaching the 1976 NO_X standard.

Installation Costs

The installation of a basic automotive turbine engine into a standard production automobile would be no more nor less complex than installing a piston engine in the same vehicle. A typical installation schematic is shown in Figure 8. Engine mounting and transmission interfacing represent no significant differences between the two installations; however, certain areas that could represent installation cost differentials were reviewed.

These areas are:

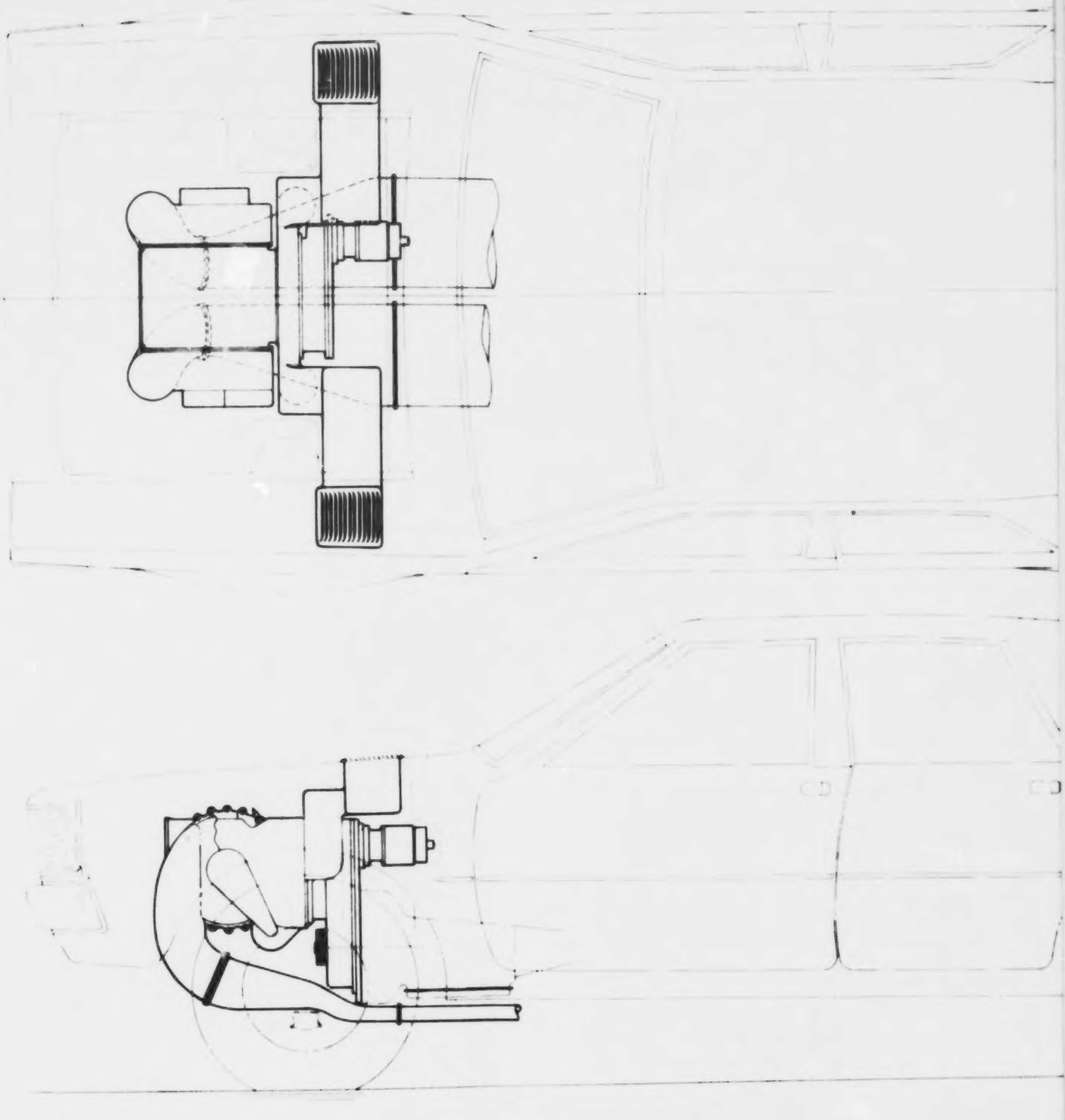
a. Cooling System

b. Intake and exhaust system

c. Vehicle accessories, electrical system, and instrumentation

d. Engine compartment environment

The piston engine cooling system requires the additional installation and connection of the radiator, hoses, fan and shroud. This requirement is eliminated with the turbine engine because the oil cooling system is an integral part of the basic engine.



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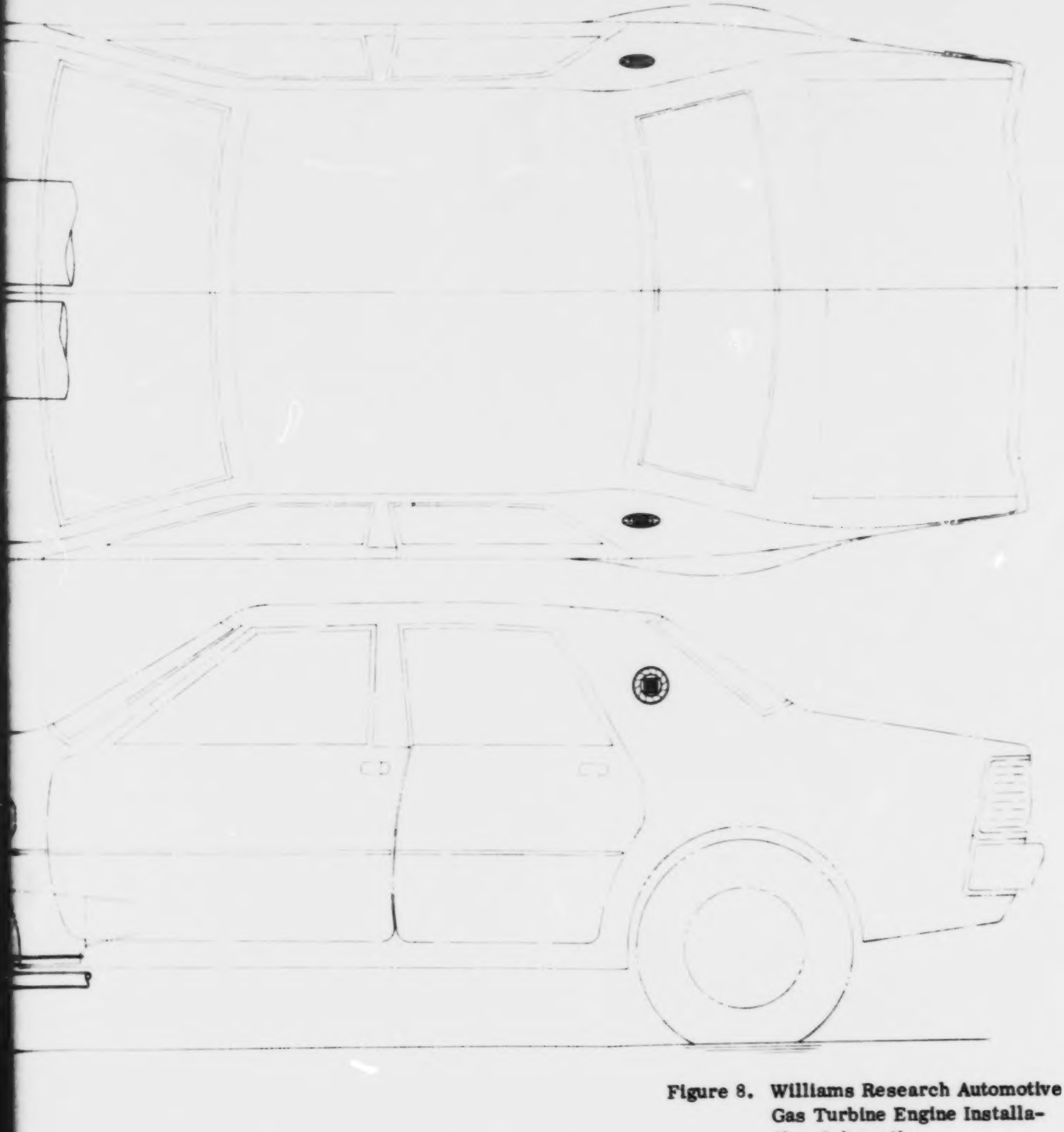


Figure 8. Williams Research Automotive Gas Turbine Engine Installation Schematic

Conversely, the air intake and silencing and exhaust systems of the turbine engine are somewhat more complex than their piston engine counterparts. It is a fair assumption then that the additional costs incurred to install the exhaust and the air intake and silencing systems for the turbine engine would be approximately equalled by the cooling system installation costs of the piston engine.

Although the engine configurations and the accessory drive locations are different, the accessory systems are essentially the same. The location of the accessories in relation to the drive pulley should constitute no difference in installation costs. Commercial alternators, air conditioning compressors, and power steering systems have been successfully used in automotive turbine engine installations. Power brake boosters modified to use pressure instead of vacuum as well as pressure operated pneumatic heater and air conditioner controls have also been used. Vehicle instrumentation and connections to the electrical power source would also be essentially the same as a piston engine installation.

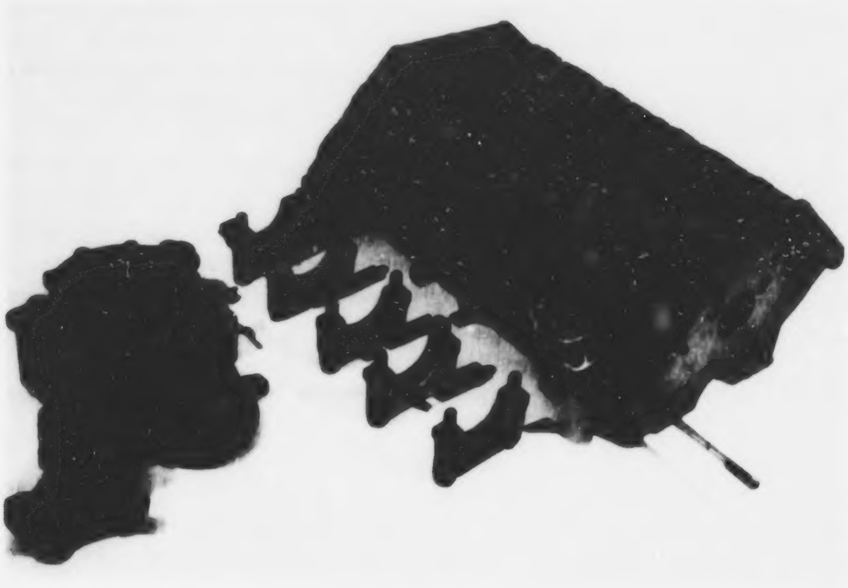
The automotive turbine engine will cause no unique problems associated with the engine compartment environment. Temperature sensitive materials and parts must be carefully located with either engine installation, but operating experience with automotive turbine engines has shown that this can be accomplished with no additional installation cost.

Relative Part Complexity

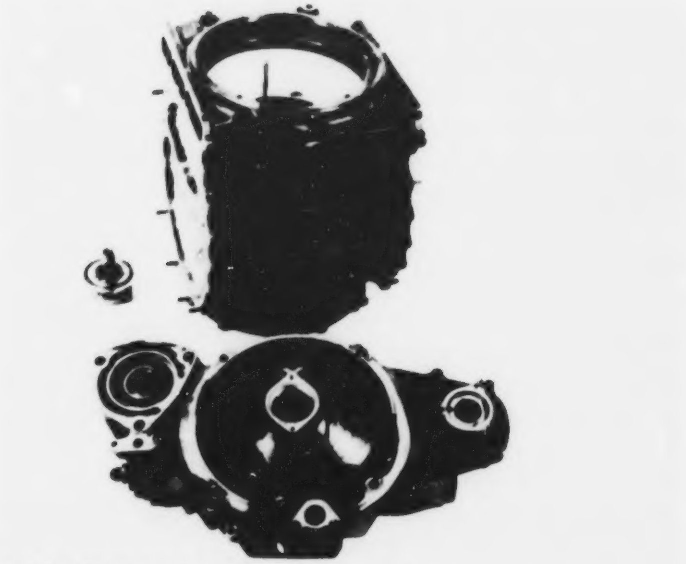
An additional area of interest is the relative complexity of the components and individual parts of both engine types. To facilitate a visual comparison of these parts, a group of illustrations have been prepared showing the engines disassembled. Where possible, an attempt was made to group the components by functions within their respective engines.

The turbine engine illustrated is the existing Williams Research prototype engine, and as such does not reflect the design changes that comprise the conceptual 1975 engine used for this economic analysis. Therefore, the illustrations show a hydromechanical fuel control, a fixed-area power turbine nozzle, a shielded ignition system, aircraft-type external oil lines, and a more complex accessory drive system. As previously discussed, the conceptual engine incorporates an electronic fuel control, a variable-area power turbine nozzle, an unshielded ignition lead and spark plug, automotive-type plumbing, and a simplified accessory drive system. The piston engine illustrated is a standard 304 cubic inch V-8 engine.

The major structural components are shown in Figure 9. While the castings for both engines require similar processes, the number of axes that require major machining operations are significantly fewer on the turbine engine housing. The turbine engine gearbox is placed to show the engine mounting face and the starter mounting pad and appears to require complex machining; however, neither of these surfaces are visible in the piston engine illustration.



Piston Engine



WR-26 Turbine Engine

Figure 9. Major Structural Components

The major, highly stressed, combustion and dynamic components are shown in Figure 10. The surfaces requiring close tolerance machining are also significantly fewer on the turbine engine parts. Wherein the piston engine incorporates five main bearings and eight connecting rod bearings; the turbine engine utilizes only five main engine bearings, resulting in fewer bearing journals. In addition, the turbine engine bearings are smaller and can be machined on a common center. The turbine engine utilizes four moving parts in this functional group (two turbines and shafts, the compressor rotor, and the fuel slinger), while the piston engine incorporates eight pistons, piston rings, wrist pins, and connecting rod subassemblies, as well as the crankshaft. All major machining on the turbine engine burner and nozzles can be accomplished on the same center, whereas the cylinder heads of the piston engine require a number of bores and flat surfaces on different centers.

The engine components that control the air and gas flow are presented in Figure 11. While the turbine engine parts encompass more hollow bulk because the gas flow is greater, they are substantially fewer, less complex, and require less precise machining than the piston engine manifolds, cam shaft, and valve train.

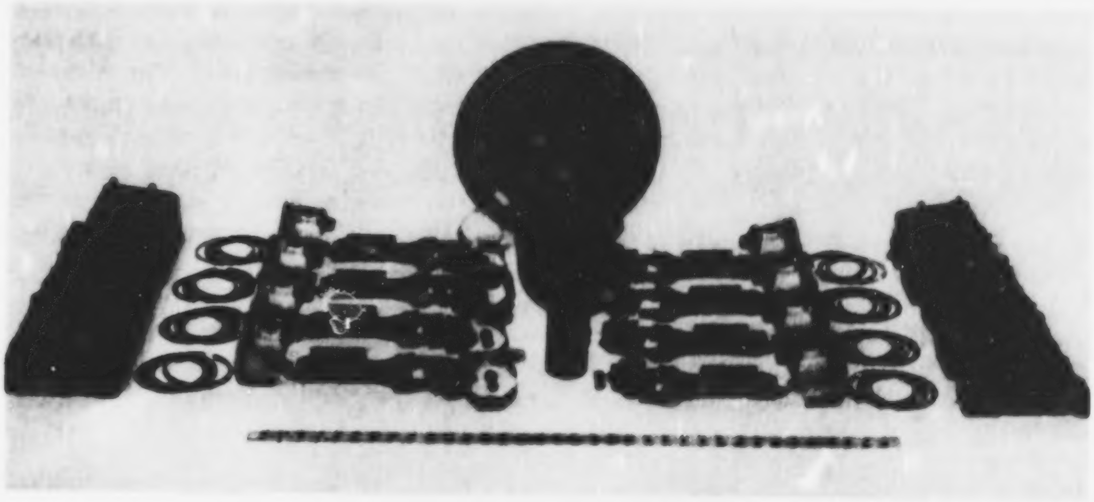
The fuel system elements, shown in Figure 12, portray a similar level of complexity for both engines. However, the addition of emission control equipment required to meet the 1976 Federal Emissions Standards would increase the complexity of the piston engine fuel system to some degree. Moreover, the turbine engine electronic fuel control, including the power turbine nozzle actuator, will appear somewhat less complex than the hydromechanical control unit shown.

The lubrication systems for both engines are very similar, Figure 13. The turbine engine oil sump is an integral part of the air intake/gearbox cover casting, shown in Figure 10; while the separate piston engine oil pan is included in Figure 13. The turbine engine oil pump housing is also an integral part of the gearbox cover casting, whereas a separate casting is used for the piston engine oil pump housing.

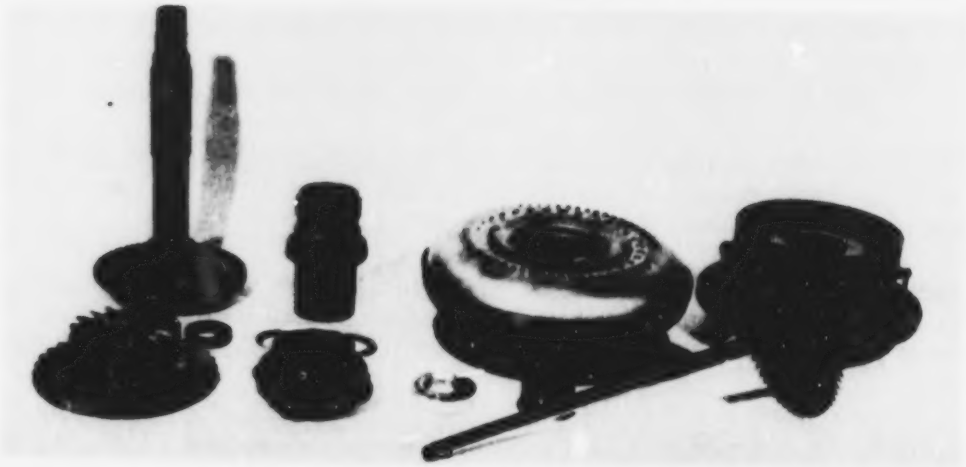
The ignition systems are portrayed in Figure 14. With the elimination of the requirement for engine timing and secondary voltage distribution, the turbine engine ignition system is obviously less complex.

The engine cooling systems, Figure 15, also illustrate the relative simplicity of the turbine engine. A relatively small heat exchanger and blower for oil cooling is used instead of the larger fan, radiator, water pump, and hoses required for the piston engine.

The gaskets, accessory drives, and miscellaneous parts are shown in Figure 16. Because of the speed reduction requirements necessary to make the turbine engine compatible with automotive applications and accessories, the engine is more complex in this functional area than the piston engine.

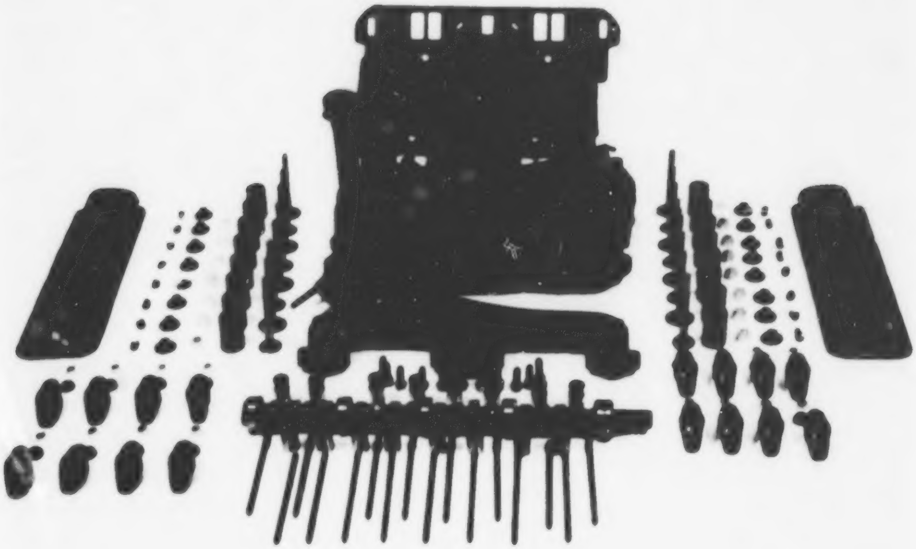


Piston Engine

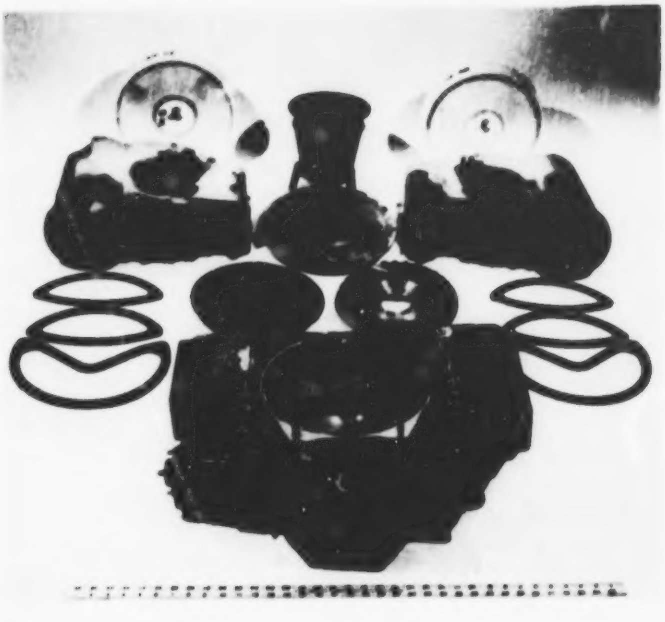


WR-26 Turbine Engine

Figure 10. Combustion and Dynamic Components

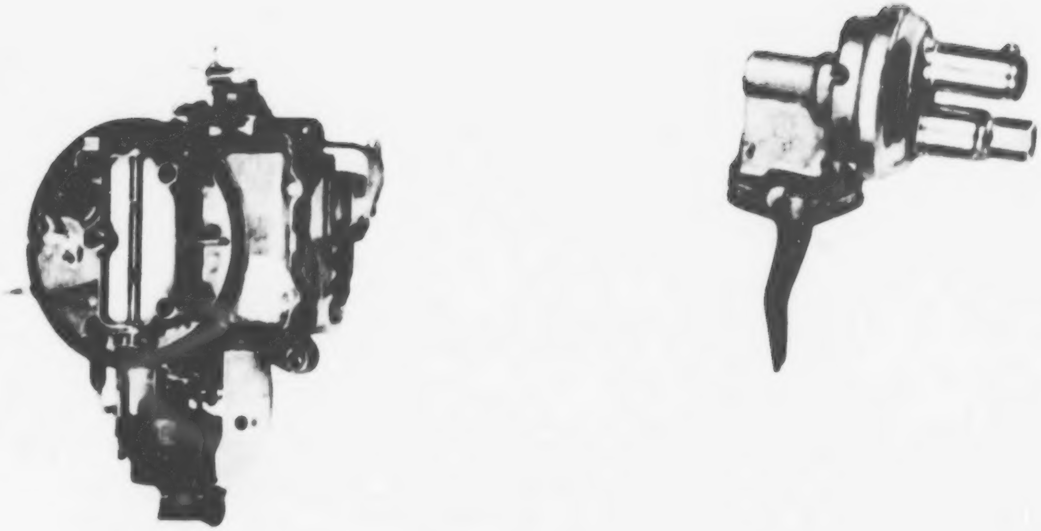


Piston Engine

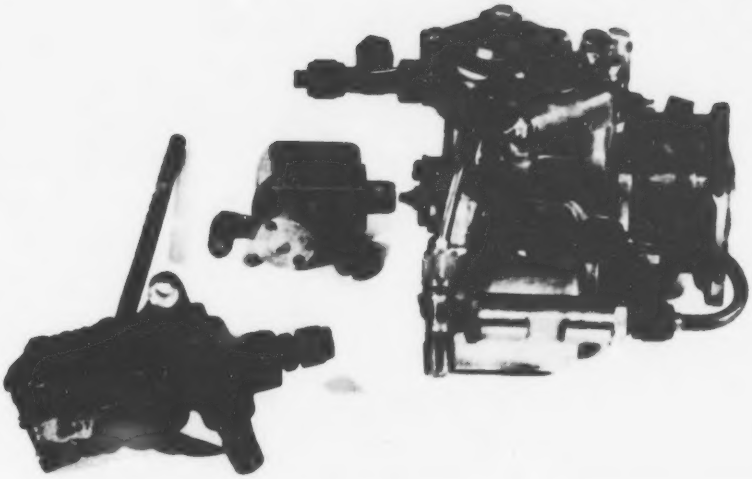


WR-26 Turbine Engine

Figure 11. Gas Control Components

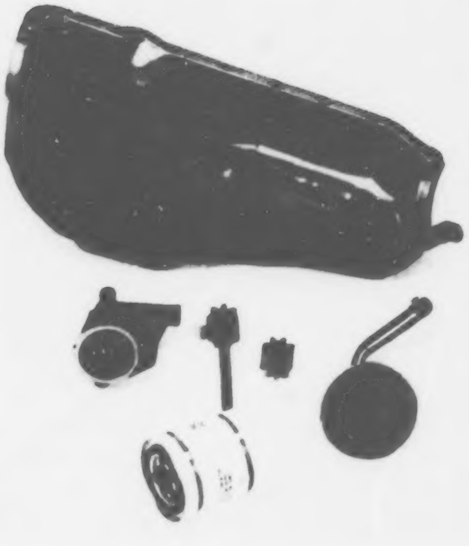


Piston Engine

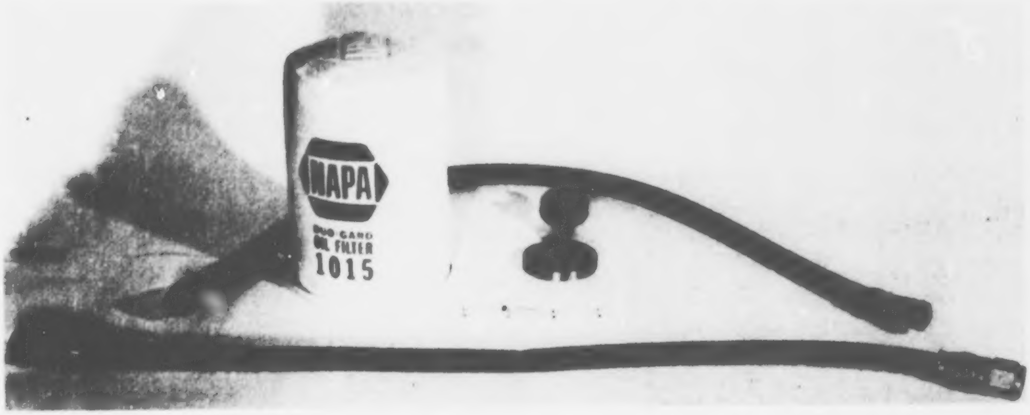


WR-26 Turbine Engine

Figure 12. Fuel System



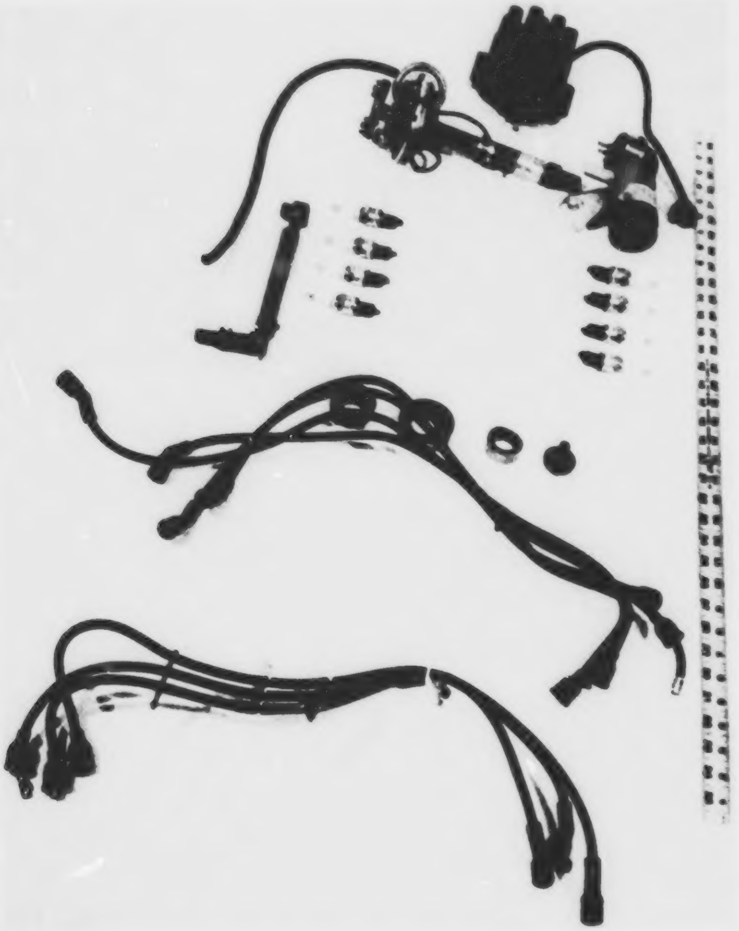
Piston Engine



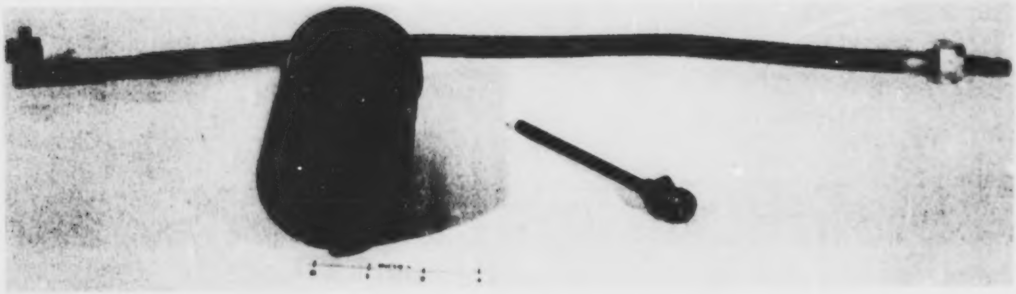
NAPA
DUO-GARD
OIL FILTER
1015

WR-26 Turbine Engine

Figure 13. Lubrication System



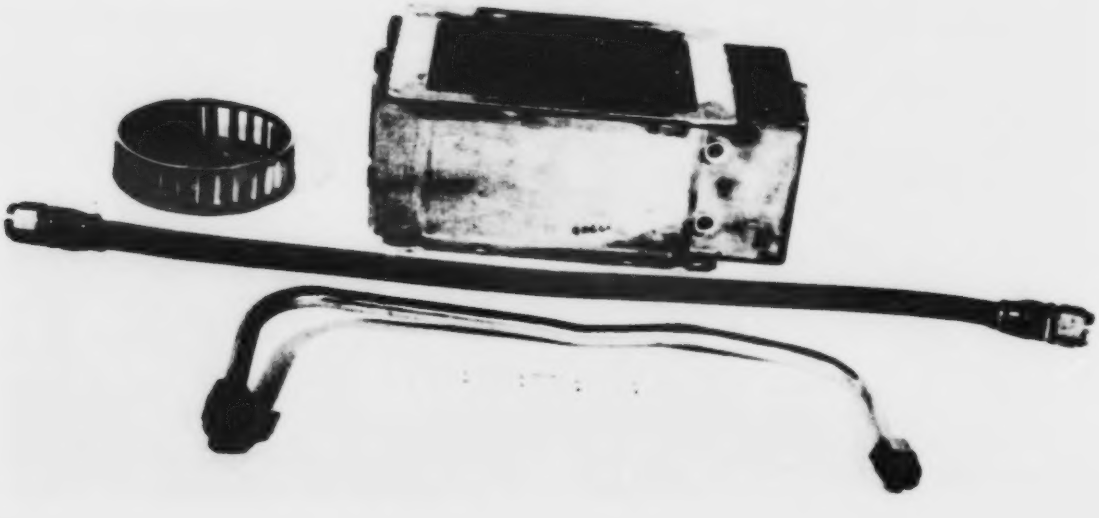
Piston Engine



WR-26 Turbine Engine

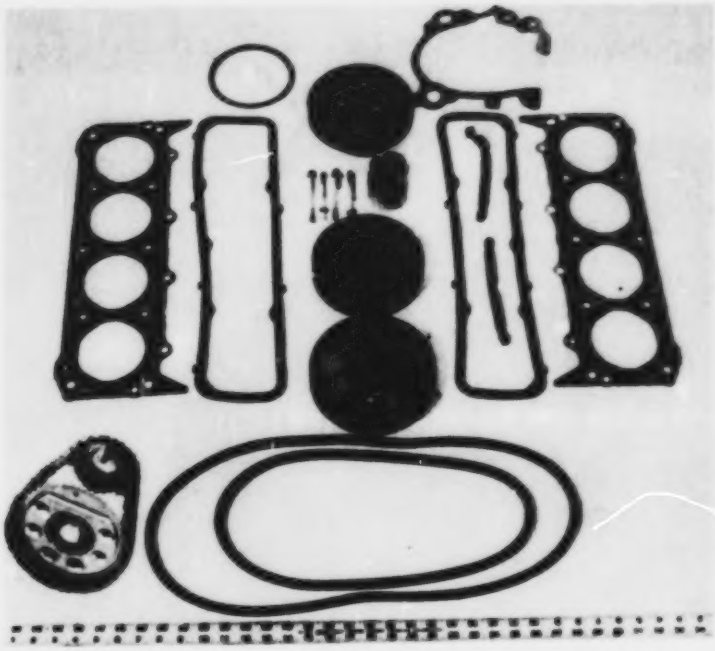
Figure 14. Ignition System

Piston Engine

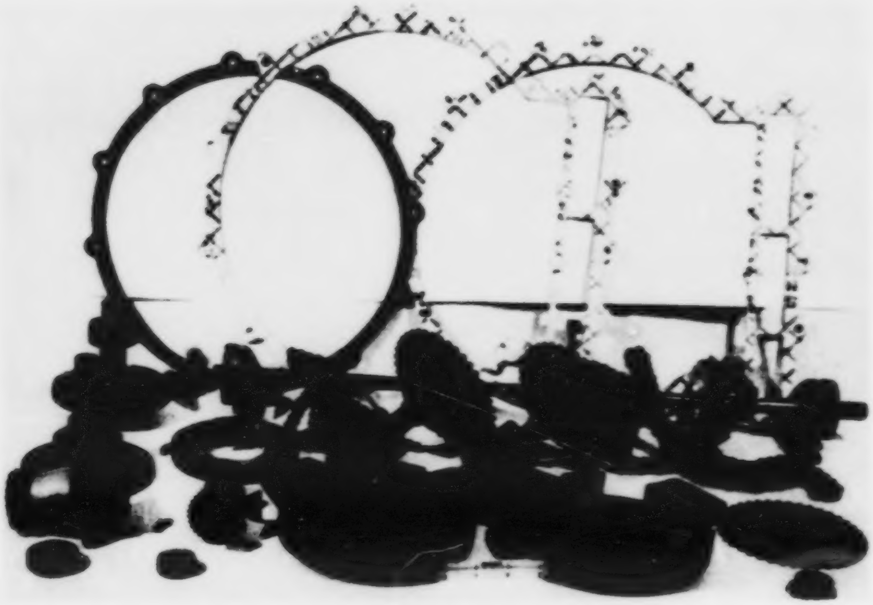


WR-26 Turbine Engine

Figure 15. Cooling System



Piston Engine



WR-26 Turbine Engine

Figure 16. Gaskets, Accessory Drives, and Miscellaneous Parts

SECTION IV

Operating Cost

FUEL COST ANALYSIS

A fuel cost analysis was conducted on the study engine to determine the total fuel consumed by a simulated turbine powered vehicle driven over a specified velocity-time schedule. The vehicle driving cycle used for this analysis is from the Uniform Simplified Engine Duty Cycle, 15 October 1971, as specified by the contract. As shown in Table 5, three modes of operation are specified: 1,750 hours of Federal Driving Cycle, 1,150 hours of Simplified Surburban Route, and 600 hours of Simplified Country Route, for a total of 3,500 hours and 105,220 miles of driving. The Federal Driving Cycle is further defined to consist of a "saw tooth" velocity-time history made up of 1,371 velocities, one second apart (see Ref. 1). The cycle is repeated until the total time is equal to the required 1,750 hours.

The non-steady state nature of the Federal Driving Cycle necessitated a computer simulation of the engine and drive train to accurately estimate the total fuel consumed.

Program Description

The engine and drive train characteristics of the gas turbine automobile were simulated by the Automotive Gas Turbine Fuel Consumption Program (AGTFCP). This identical automotive system was also simulated with the EPA Medium Size Spart Ignition Engine (I.C. engine) by the Automotive Spark Ignition Engine Fuel Consumption Program (AGTFCP.IC). These programs calculated the total fuel consumed as the automobile was driven over the specified velocity-time schedule. The programs accounted for automatic transmission shifts, torque converter slippage, drive train friction and inertia, accessory power extraction, aerodynamic drag and rolling resistance.

Input Options

The input options allow a wide range of fuel, engine, vehicle and drive train characteristics to be used. These options are:

a. Velocity-Time Schedule. The velocity-time schedule over which the simulated vehicle is driven can be any series of velocities separated by equal time increments.

TABLE 5. VEHICLE DRIVING CYCLES

	Avg. Speed	Hours	% of Time
a. Federal Driving Cycle	19.84	1750	50
b. Simplified Surburban Route (equal times at constant 20, 30, and 40 mph speeds)	30.00	1150	33
c. Simplified Country Route (equal times at constant 50, 60, and 70 mph speeds)	60.00	600	17
Totals		3500	100

b. **Vehicle.** The following vehicle characteristics were entered: drive wheel diameter, aerodynamic drag coefficient x frontal area product, location of the vehicle center of gravity with respect to the wheels, vehicle total weight, drive wheel location (front, rear, all four), friction coefficient, and rolling resistance coefficient.

c. **Drive Train.** The following drive train characteristics are entered: the gear reduction between the power turbine and torque converter (1 in the case of IC Engine), the automatic transmission and differential gear ratios and their respective mechanical efficiencies and the polar moments of inertia of the power turbine, torque converter and vehicle wheels.

The Borg Warner Model "S" torque converter was used in this study. The torque converter performance characteristics are presented in Figure 17. This data was used to obtain the more useable characteristics shown in Figure 18. The data as plotted in Figure 18 were used in the programs to obtain the torque converter characteristics.

d. **Accessory Power Extraction.** The accessory power extraction limits were placed in subroutine (ACCESP) as a function of speed (see Ref. 2, Section 14). The input option of air conditioning "off" and "on" is available.

e. **Fuel.** The fuel specific weight and lower heating values are accepted as input.

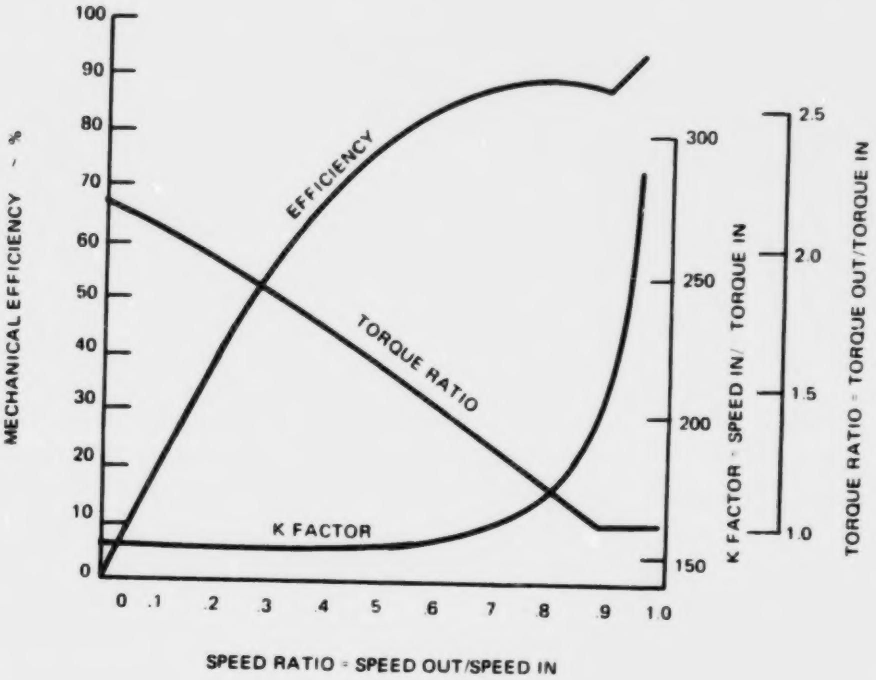


Figure 17. Borg Warner Model S Torque Converter Characteristics

f. Engine Characteristics.

(1) Gas Turbine:

The non-dimensional power and fuel flow performance were placed in subroutine (Engine) in the form of second order polynomials. This engine performance is presented in Figures 19 and 20.

(2) I.C. Engine:

The non-dimensional power and fuel flow performance presented in Figures 21 and 22 were obtained from the Medium Size Engine Fuel Economy Map.

Since there is no gas generator in the case of the I.C. Engine unit, the gas generator speeds were given the fictitious values. Unlike the gas turbine case, where quadratic equations were put in the Engine subroutine to calculate the horse power for a given value of speed, the data were put in a table form and then the equations incorporated in the Engine subroutine calculated the values of horse power for a given value of I.C. Engine speed. A straight line was assumed between the consecutive data points.

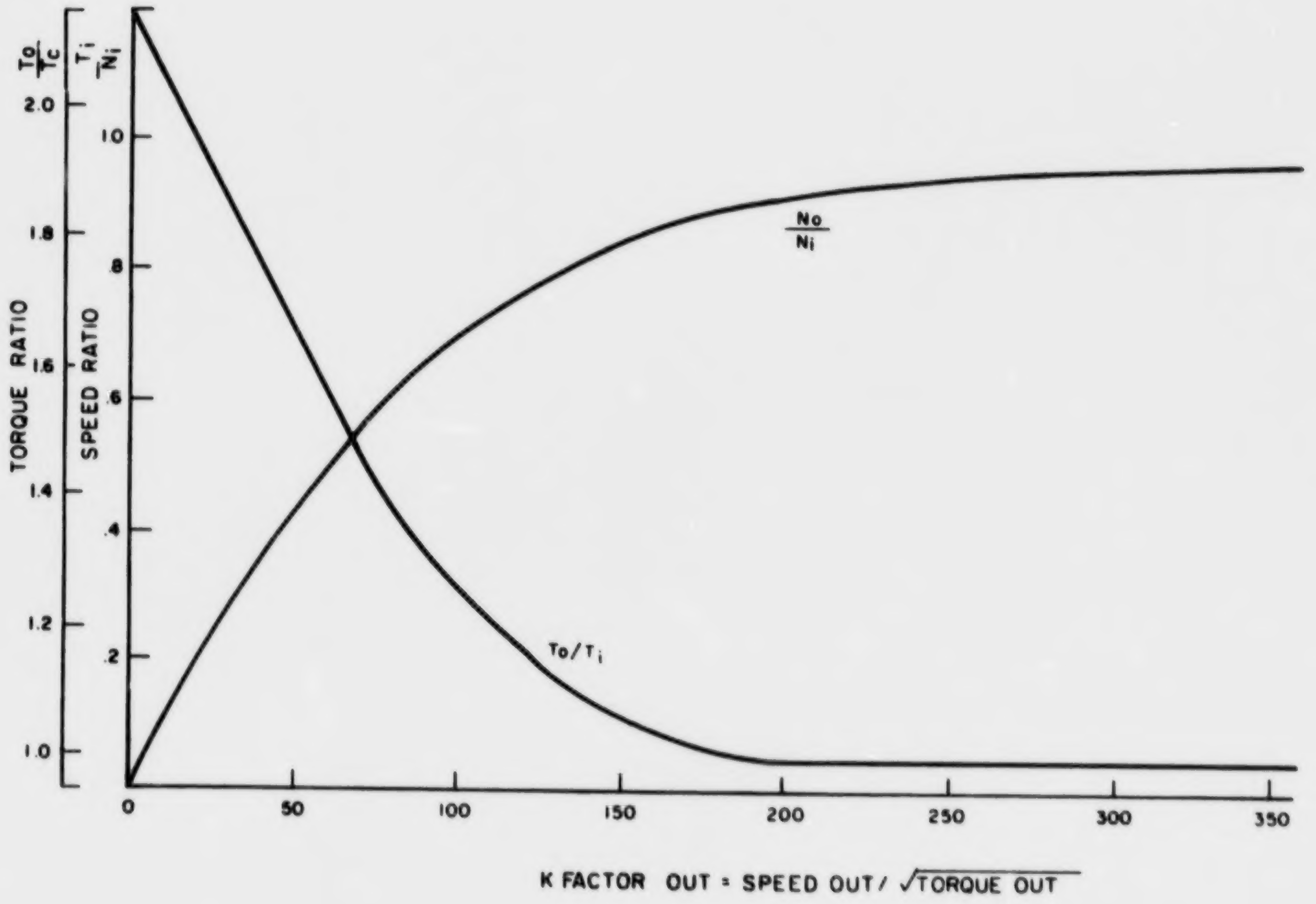


Figure 18. Borg Warner Model S Torque Converter Characteristics

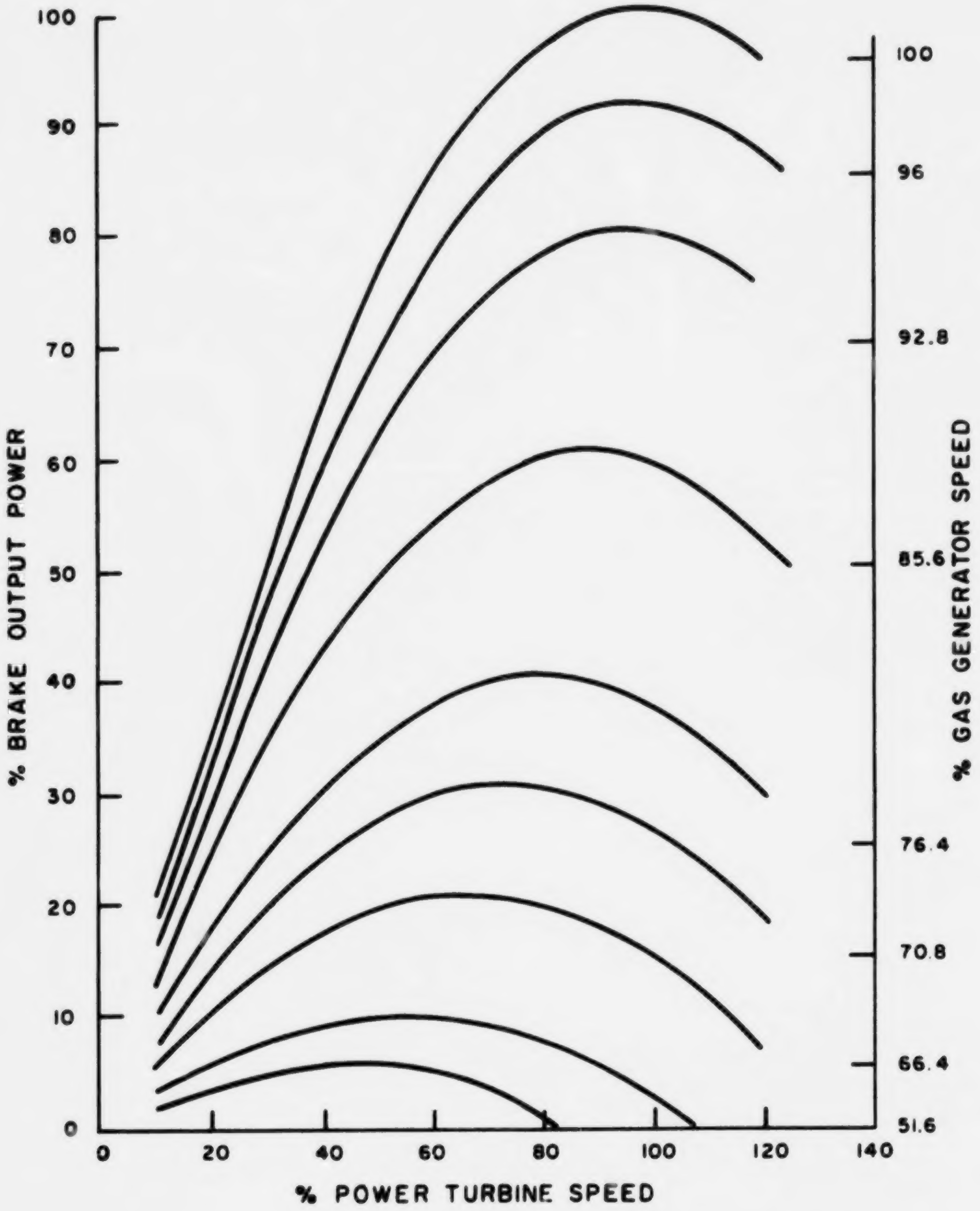


Figure 19. Regenerative Automotive Gas Turbine % Output Power vs % Power Turbine Speed and % Gas Generator Speed

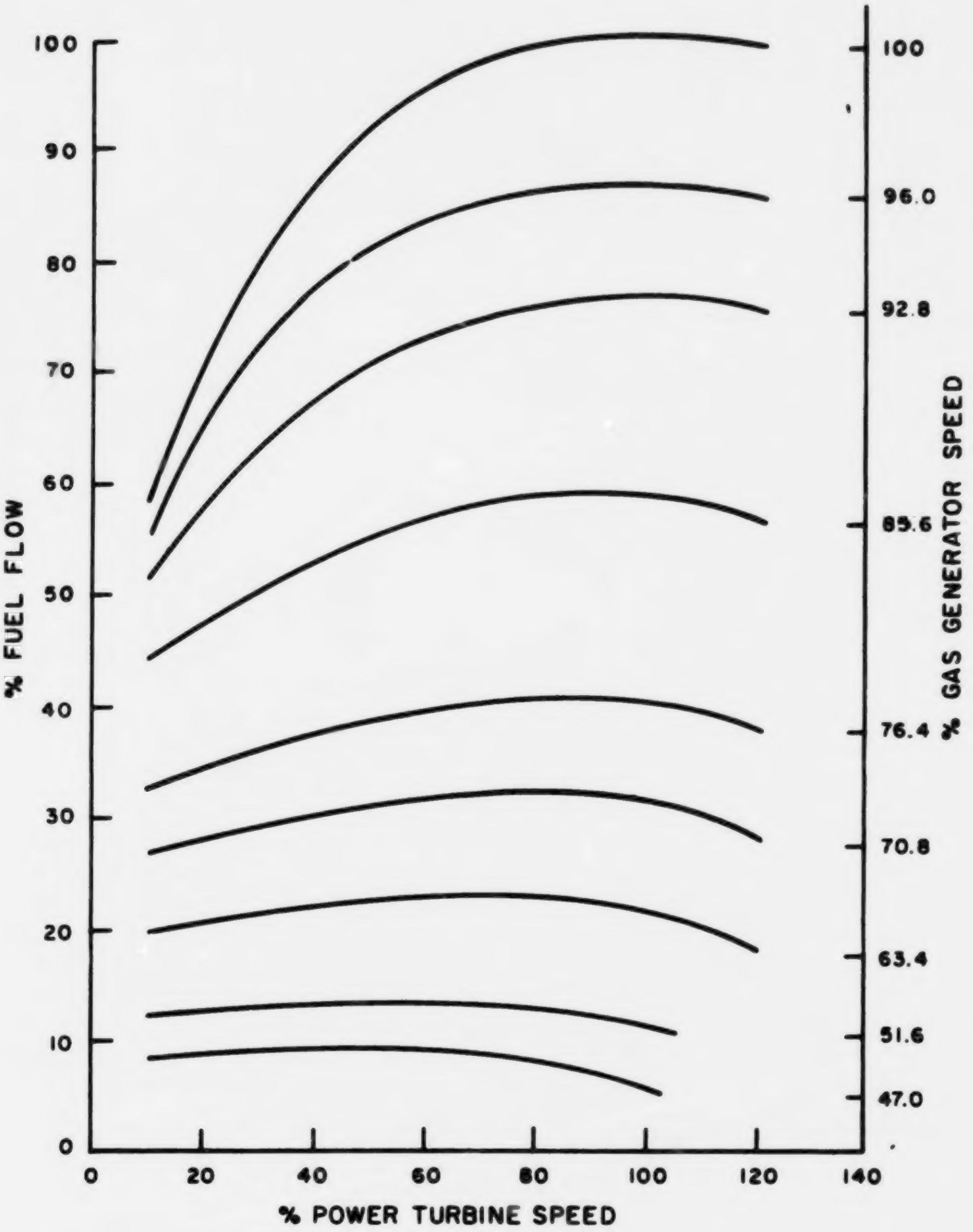


Figure 20. Regenerative Automotive Gas Turbine % Fuel Flow vs % Power Turbine Speed and % Gas Generator Speed

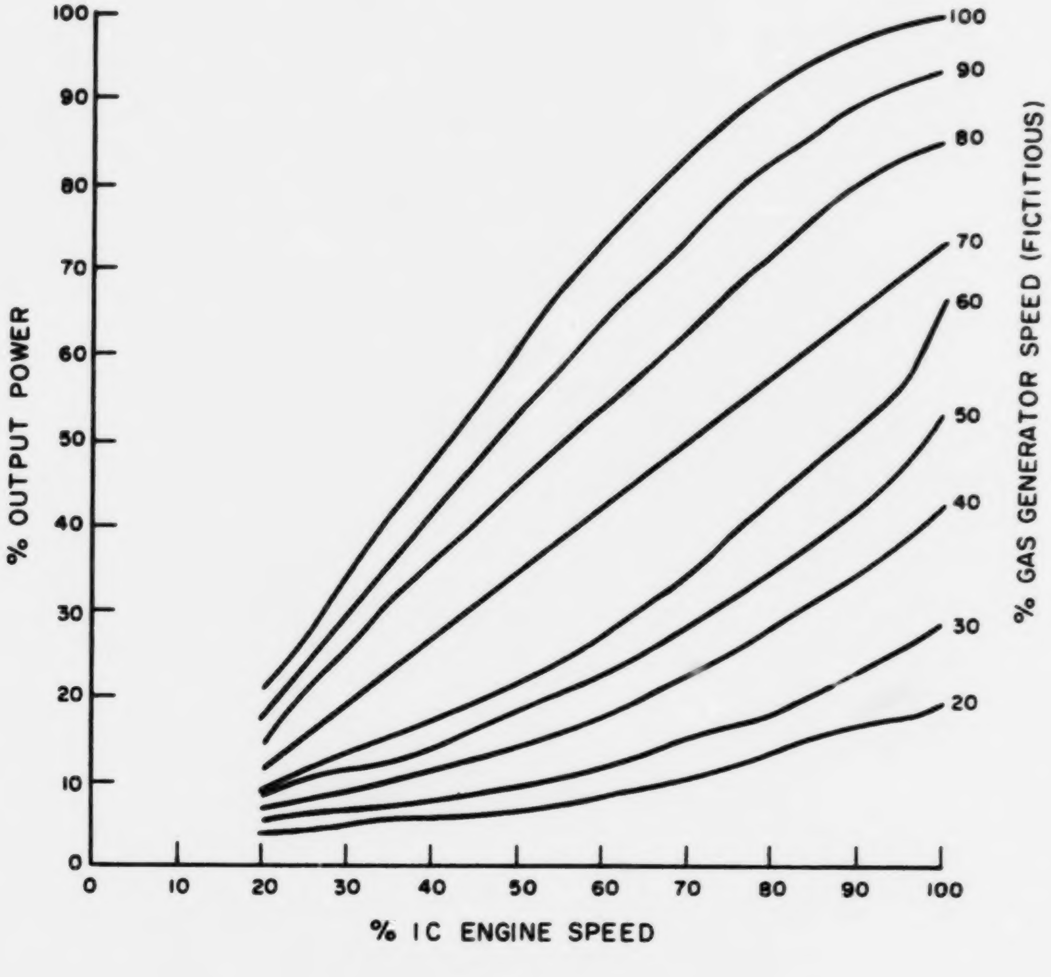


Figure 21. % Output Power vs % I.C. Engine Speed

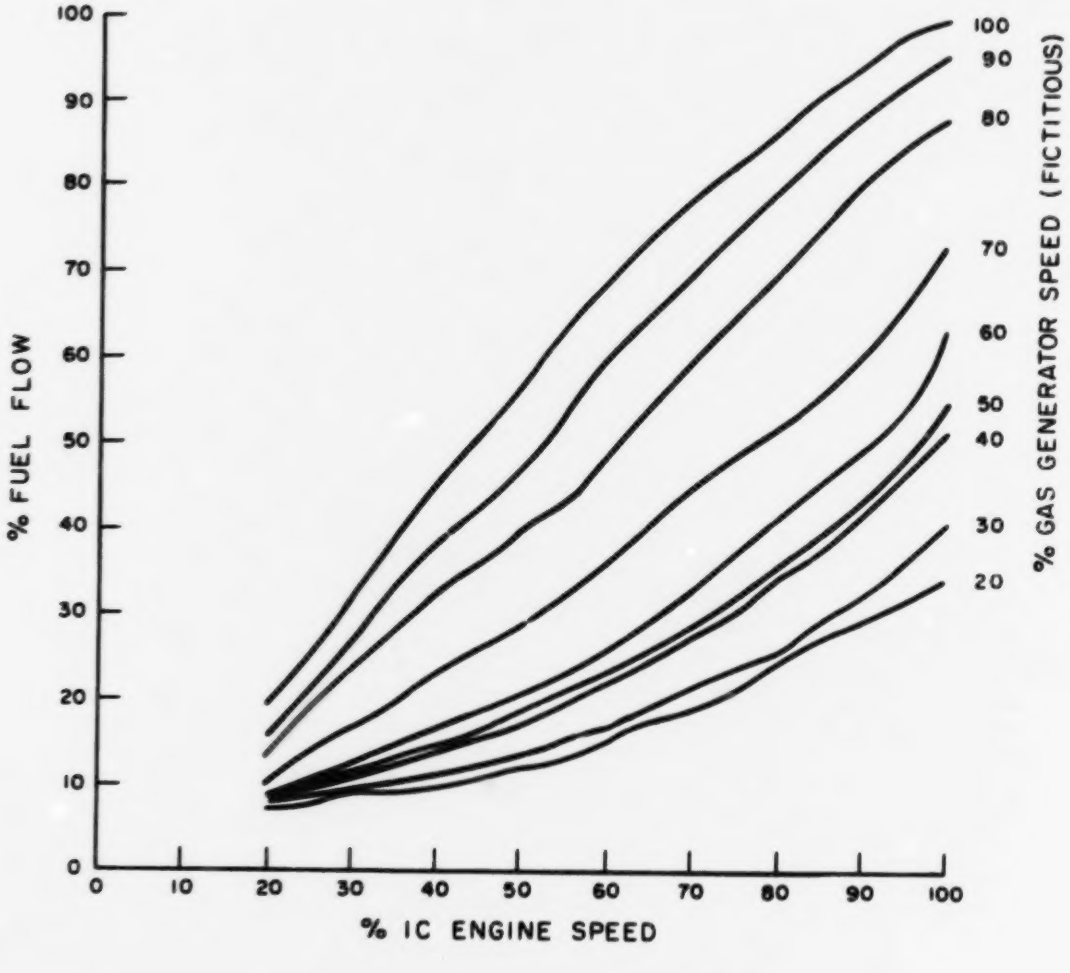


Figure 22. % Fuel Flow vs % I.C. Engine Speed

The 100% design values of output power and fuel flow are an input option and serve to fix the scale of their corresponding non-dimensional values. All engine speeds were treated on a percentile basis throughout the program with one exception. A nominal 100% design power turbine or I.C. Engine speed is required as input to allow calculation of the engine inertial load during acceleration. This nominal engine design speed in conjunction with the overall high gear ratio also serves to align the maximum power curve with the road load power curve. The intersection of these two curves defines the maximum steady-state vehicle velocity.

Method of Analysis

The basic assumption inherent in this program is that the vehicle is capable of following exactly the velocity-time schedule set for it. Exceptions to this rule are discussed subsequently in the fuel cost analysis. Based on this assumption, the acceleration response rate of the gas generator and the fuel control schedule were ignored, and all fuel consumption calculations were based on steady-state part power engine performance. The steady-state fuel flow data was stored in subroutine (ENGINE) as a function of engine speed and output power. An average velocity was calculated for each time interval in the velocity-time schedule. For a given average velocity, the required engine speed and road load power was determined and used in subroutine (ENGINE) to obtain the fuel consumed over the time increment.

For those time increments where acceleration was indicated, the additional fuel consumed was accounted for by computing the increase in kinetic energy of the vehicle and adding this power to the steady state power used in subroutine (ENGINE). The acceleration power was first increased by a "mass factor", which accounted for the inertial resistance of the drive train components including the engine itself.

One acceleration effect that was not directly accounted for was regenerator temperature lag in the case of the gas turbine. During acceleration the regenerator hot side lags behind the instantaneous steady-state temperature and the engine must use more fuel to make up the difference. This effect was compensated for in the following way. During zero throttle deceleration, the engine normally follows a minimum fuel/air ratio line down to idle. However, in the program the engine was forced to follow the road load power curve during decelerations. The resulting additional fuel consumed during deceleration was assumed to compensate for the omission of the regenerator temperature lag fuel increment during acceleration.

Program Tests

Maximum Acceleration. A point may be reached in the velocity-time schedule where an acceleration torque is required that exceeds the drive wheel friction limit. If this occurs, an error message is printed, and the program continues with the assumption that no wheelspin has occurred. This error message indicates that the assumed weight transfer and tire friction characteristics of the vehicle must be improved.

Maximum Power. A point may be reached in the velocity-time schedule where the required power exceeds the available power. If this occurs, an error message is printed, and the program continues with the required power set equal to the maximum available power. This error message indicates that the assumed maximum engine power must be increased or the vehicle weight reduced.

Maximum Velocity. For each engine-vehicle combination investigated, the program calculates the maximum steady-state velocity possible with the power and gearing available.

Program Limitations

Vehicle Weight Changes. The program does not account for vehicle weight changes due to fuel burn off. A reasonable approximation of this effect can be made by using a vehicle weight half way between a full fuel tank and a typical minimum level, such as 1/4 full.

Road Grades. No provision has been made within the program to account for road grades. (The Federal Driving Cycle is based on level roads.) This feature could be added to the program by entering a grade factor to be applied to the rolling resistance portion of the road load power curve.

PROGRAM LOGIC

Figure 23 presents a simplified flow chart indicating the major calculations and all iterative loops. The equations involved in the major calculations are described below.

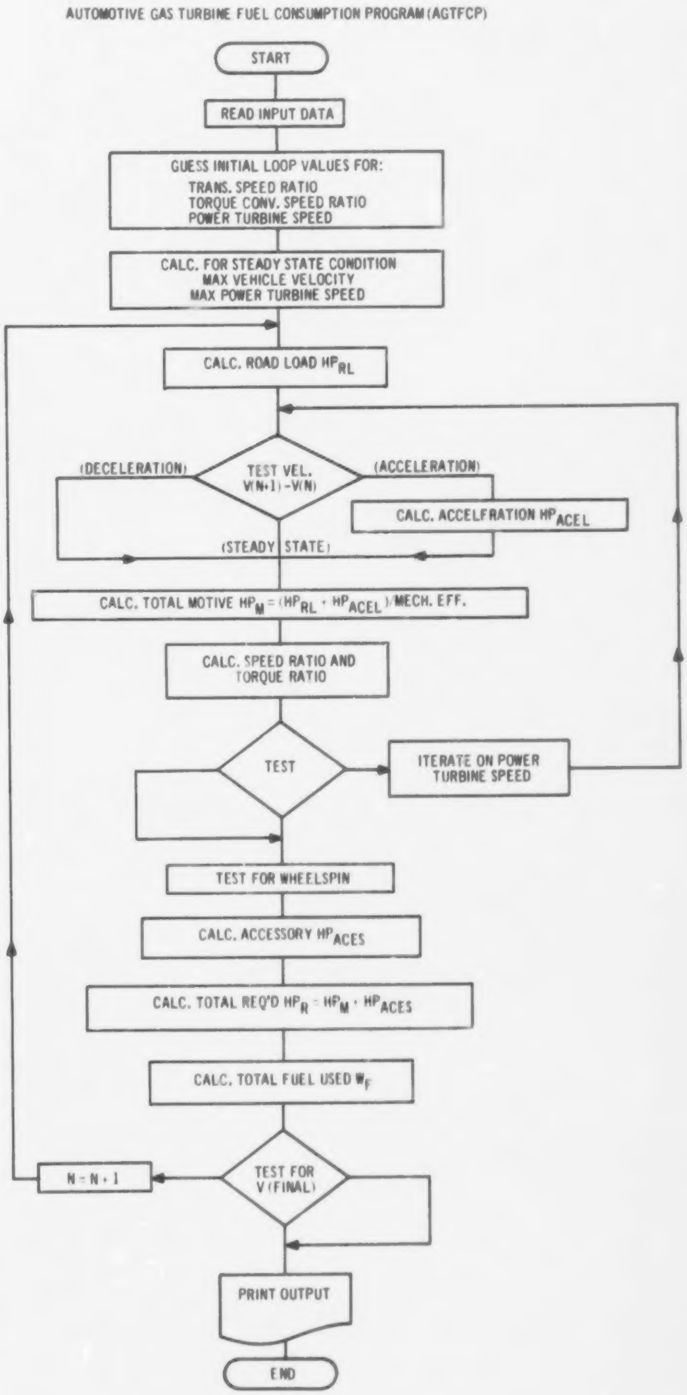

AUTOMOTIVE GAS TURBINE FUEL CONSUMPTION PROGRAM (AGTFCP)
START
READ INPUT DATA
GUESS INITIAL LOOP VALUES FOR:
TRANS. SPEED RATIO
TORQUE CONV. SPEED RATIO
POWER TURBINE SPEED
CALC. FOR STEADY STATE CONDITION
MAX VEHICLE VELOCITY
MAX POWER TURBINE SPEED
CALC. ROAD LOAD HP$_{RL}$
(DECELERATION)
TEST VEL. V(N+1) - V(N)
(ACCELERATION)
CALC. ACCELFRATION HP$_{ACEL}$
(STEADY STATE)
CALC. TOTAL MOTIVE HP$_M$ = (HP$_{RL}$ + HP$_{ACEL}$)/MECH. EFF.
CALC. SPEED RATIO AND TORQUE RATIO
TEST
ITERATE ON POWER TURBINE SPEED
TEST FOR WHEELSPIN
CALC. ACCESSORY HP$_{ACES}$
CALC. TOTAL REQ'D HP$_R$ = HP$_M$ + HP$_{ACES}$
CALC. TOTAL FUEL USED W$_F$
N = N + 1
TEST FOR V (FINAL)
PRINT OUTPUT
END

Figure 23. Automotive Gas Turbine Fuel Consumption Program (AGTFCP)

1. AERODYNAMIC DRAG:

```
FD = .09029 * CDAF * PA * VA(N) **2/TA
```

where:

FD = Aerodynamic drag-lbs.
CDAF = Drag coefficient x frontal area-sq. ft.
PA = Ambient pressure-psia
VA(N) = Average velocity-mph
TA = Ambient temperature-°R

2. ROLLING RESISTANCE: (Section 8, Reference 2)

```
FR = (W/65) * (1+.0021 * VA(N) + .000026 * VA(N) **2)
```

where:

FR = Rolling resistance-lbs.
W = Vehicle weight-lbs.

3. ROAD LOAD POWER:

```
HPRL = (FD+FR) * VA(N)/374.9)
```

where:

HPRL = Road load horsepower

4. DRIVE TRAIN INERTIA MASS FACTOR: (Page 39, Reference 3)

```
FM = 1+(1545.6/(W*DDW**2) * [DWI+PTI*(S2A/S5) + TCI* (S3(J)/S5)]
```

where:

FM = Mass factor
DDW = Drive wheel diameter-in.
DWI = Sum of road wheel polar moments of inertia-in.-lb.-sec.^{2}
PTI = Power turbine polar moment of inertia-in.-lb.-sec.^{2}
TCI = Torque converter polar moment of inertia-in.-lb.-sec.^{2}
S2A/S5 = Speed ratio between power turbine and rear axle
S3(J)/S5 = Speed ratio between torque converter and axle shaft

5. **ACCELERATION POWER:**

```
HPAC = FM*W* (V(N+1) **2-V(N)**2)/(35391*DT)
```

where:

HPAC = Acceleration horsepower
DT = Time increment-sec.
V(N+1) = Velocity at end of DT-mph
V(N) = Velocity at start of DT-mph

6. **VEHICLE WEIGHT TRANSFER DURING ACCELERATION:**
(Page 60, Reference 3)

Front wheels driving:	`WT(1) = (LR+F*H)/(L+MU*H)`
Rear wheels driving:	`WT(2) = (LR-F*H)/(L-MU*H)`
Four wheels driving:	`WT(3) = 1`

where:

WT = % of vehicle weight on drive wheels
LR = Vehicle CG distance from rear axle-%L
L = Vehicle wheel base
H = Height of vehicle CG above ground-%L
MU = Tire friction coefficient on road
F = Tire rolling resistance coefficient

7. **MAXIMUM VEHICLE ACCELERATION:** (Page 60, Reference 3)

```
AMAX = 32.2 * (WT(IDWL) * MU-F)/FM
```

where:

AMAX = Max. acceleration-ft./sec.^{2}
IDWL = Drive wheel location-1, 2, 3

Program Results

The estimated fuel consumption obtained from programs for the 105,220 miles of driving over the specified velocity-time schedule is shown in Table 6, column A. The test conditions assumed for the data were as follows:

Ambient Pressure = 14.7 psia
Ambient Temperature = 85°F
Vehicle Test Weight = 3160 lb.
Engine Max Power @ 85°F = 116.6 HP
Engine SFC @ 85°F (Gas Turbine) = 0.415
Engine SFC @ 85°F (I.C. Engine) = 0.565
Accessory Power Extraction - @ Idle = 4.0 HP
(Including Airconditiong) - @ Max = 15.0 HP

The I.C. engine data provided by EPA (Medium Size Engine Fuel Economy Map) was for an engine of considerably more power than required to give the performance called for. This map was, therefore, scaled to the above test conditions.

TABLE 6. ESTIMATED FUEL CONSUMPTION

Mode of Operation	Speed (MPH)	Time (HRS)	Miles	Gas Turbine		I.C. Engine	
				Fuel Used (Gal.)	M.P.G.	Fuel Used (Gal.)	MPG
1. Federal Driving Cycle	19.84*	1750.0	34,720	2552.9	13.60	2521.4	13.77
2. Simplified Suburban Route	20.0 30.0 40.0	383.33 383.33 383.33	7,667 11,500 15,333	491.1 493.1 614.5	15.61 23.32 24.95	443.7 518.7 715.5	17.28 22.17 21.43
3. Simplified Country Route	50.0 60.0 70.0	200.0 200.0 200.0	10,000 12,000 14,000	411.5 548.2 712.5	24.30 21.89 19.65	508.9 686.5 930.8	19.65 17.48 15.04
TOTAL		3500.0	105,220	5823.8	18.07	6325.5	16.63
Total Fuel Cost @ 31¢/Gal.				$1805.37		$1960.90	

*Average Value

MAINTENANCE AND REPAIR COSTS

The analysis of maintenance and repair costs associated with owning a 1975 turbine engine powered automobile and the comparison of these costs with the expense of owning the same automobile powered by a piston engine was initiated by first defining those areas of each installation that are significantly different.

As discussed previously in this report, the turbine engine is conventionally installed in the front of the vehicle and drives the rear wheels through a standard torque converter and automatic transmission. In addition, the electrical system, power steering system, power brake system, air conditioning system, and other vehicle accessories would not be expected to differ significantly, regardless of the type of powerplant used. Therefore, only the maintenance and repair costs of the engine and engine related systems were considered in this analysis.

This may be a slightly conservative approach because of the lower levels of vibration and lower torque rate changes associated with the turbine engine. However, a comparison of the relative stresses caused by vibration and torque changes on drive train elements and vehicle accessories cannot be made with any degree of credibility at this time.

Overhaul and Unscheduled Repair

Modern piston engines operated in "normal" passenger car service can be expected to operate in excess of 100,000 miles without requiring a major overhaul (see Ref. 4). To be competitive in the automotive market, any automotive gas turbine engine intended for similar service must exhibit a design life in excess of this figure. Therefore, no engine overhaul costs are included in the estimate of lifetime operating costs. Acknowledging that random failures do occur and that motorists occasionally find it necessary to have piston engines overhauled requires that some evaluation of the relative costs be attempted. Assuming that an overhaul essentially requires a complete disassembly and reassembly of the engine, the manufacturing cost estimate previously discussed indicates a substantially lower assembly labor requirement for the build up of a turbine engine than that required for the build up of a piston engine. In consideration of this, a generalization can safely be made that a random overhaul, occurring with the same probability with either engine, would cost the owner less if his automobile is turbine engine powered.

Other random failures associated with the piston engine will undoubtedly have their equivalent failures on the automotive turbine engine. However, because of fewer moving parts, reduced vibration levels, a simplified ignition system, the elimination of the engine cooling system, and no add-on emission control system; the cost of these repairs will also favor the turbine engine. Again, these factors were not considered in calculating the operating cost comparison between the two engine types. In addition, no attempt was made to predict the repair or replacement costs associated with the equipment required for the piston engine to meet the 1976 Federal Exhaust Emissions Standards.

An additional item contributing to random repair costs that must also be considered is the exhaust system. Depending on the climate and driving cycle, present piston engine powered vehicles require a minimum of one complete exhaust system replacement during their lifetime. This replacement is usually a result of corrosive failure. Experience with aluminum exhaust ducts on turbine powered vehicles operating in severe climatic conditions has indicated that this type of failure is significantly reduced with turbine engines. The principal threat to the system, therefore, is damage from exterior sources, which is usually repairable without replacing the entire system. Due to the lack of a reliable method of predicting and quantifying these factors, their effects have also been omitted from the lifetime operating cost comparison.

Scheduled Maintenance

Periodic maintenance services required to ensure the proper operation, performance, and reliability of the engine and engine related systems constitute the most significant area of maintenance and repair cost differences between the conventional piston engine and the turbine engine powered automobile. To estimate and compare the lifetime costs associated with these services, maintenance schedules were developed for both engines.

The major automobile manufacturers include with each new automobile a detailed set of instructions specifying the scheduled maintenance and service requirements. In addition, the 1972 vehicle service instructions include a separate publication specifying the services required to ensure the correct operation of the exhaust emission control components. By averaging the varying requirements of three major U.S. automobile manufacturers as published in their Owner's Manuals for an eight cylinder intermediate sedan, a composite maintenance schedule was developed for the piston engine. Six metropolitan Detroit new car dealers were then surveyed to obtain average retail prices for these services. Without exception, these dealers quoted a total price for most of the scheduled maintenance under the heading of a Tune-Up or 12,000 Mile Inspection, etc. Although the prices quoted were fairly consistent for what appeared to be essentially identical work, this Flat Rate approach prevents the segregation of costs for individual services. The Typical Maintenance Schedule, Table 7, shows the frequency and the average retail prices for the scheduled maintenance services on a piston engine.

TABLE 7. TYPICAL MAINTENANCE SCHEDULE

1972 STANDARD 8 CYLINDER INTERMEDIATE SEDAN (AUTOMATIC TRANSMISSION)

Interval* Miles/Months	Description-Engine Related Maintenance	Average Retail Price
4000/6	Change engine oil, clean crankcase breather or filter, apply manifold heat control valve solvent.	$ 4.25
8000/-	Replace engine oil filter	$ 5.50
12,000/12	Replace fuel filter.	$ 2.50
	Ignition, fuel and emission system tune up and inspection including replacement of spark plugs and ignition points.	35.20
		$ 37.70
24,000/24	Replace air cleaner filter element	$ 4.90
	Replace PCV valve	2.20
	Flush cooling system and replace coolant	9.10
		$ 16.20

*Whichever comes first.

Assuming that the vehicle will accumulate a total of 105,000 miles over a ten year period at the rate of 10,500 miles per year and using the average retail prices from the Typical Maintenance Schedule, the Engine Related Lifetime Maintenance Cost Estimate, Table 8, was developed for the piston engine. All prices for scheduled maintenance services were based on a standard eight cylinder, automatic transmission, 1972 intermediate sedan.

A similar maintenance schedule, Table 9, was developed for a 1975 turbine engine powered automobile. This schedule was based on past experience with Williams Research regenerative gas turbine engines and vehicle installations; the recommendations of Mr. R. N. Penny, former director of automotive turbine activities at British-Leyland Gas Turbines, Ltd.; and the experience gained from the Chrysler automotive turbine engine program of the mid-1960's. In estimating the retail prices that would be charged for the scheduled maintenance services, the following guides were established:

a. The average retail labor rate charged would be $9.00 per hour.

b. Fuel and oil filter elements are identical to present automotive elements.

TABLE 8. ENGINE RELATED LIFETIME MAINTENANCE COST ESTIMATE

1972 STANDARD 8 CYLINDER INTERMEDIATE SEDAN

Based on:
1. Typical Maintenance Schedule
2. 105,000 Total Accumulated Miles
3. 10 Years Total Life (10,500 Miles/Year)

Interval Miles/Months	Lifetime Number Of Intervals Based On		Average Retail Price	Total Lifetime Cost
	Miles	Months		
4000/6	26.25	-	$ 4.25	$ 111.56
8000/-	13.125	-	$ 5.50	$ 72.19
12,000/12	-	10	$ 37.70	$ 377.00
24,000/24	-	5	$ 16.20	$ 81.00
		Total Engine Related Lifetime Scheduled Maintenance Cost.		$ 641.75

TABLE 9. PROJECTED MAINTENANCE SCHEDULE
1975 AUTOMOTIVE GAS TURBINE ENGINE

Interval* Miles/Months	Description-Engine Related Maintenance	Estimated Retail Price
12,000/12	Clean Air Filter Element	$ 1.80
	Replace Fuel Filter	2.50
	Replace Oil Filter (includes addition of 1 Qt. oil)	8.50
	Clean Compressor	1.35
	Check and Adjust Control System	4.50
		$18.65
24,000/24	Change Engine Oil (Synthetic Turbine Oil)	$12.00
	Replace Air Filter Element	9.80
		$21.80

*Whichever comes first.

c. The retail price of the air filter element (or elements) would be twice that of a present automotive element.

d. Compressor cleaning material would cost $.25.

e. Synthetic turbine oil would cost $3.00 per quart at automotive volumes.

f. Compressor cleaning would require 0.1 hours, air filter cleaning would require 0.2 hours, and a fuel control system check would require 0.5 hours.

Operating experience with automotive gas turbine engines using petroleum base as well as synthetic turbine oils has shown that contamination of the oil is minimal; and that which does occur is almost exclusively of a solid or particulate nature, which can be filtered out. Acid formation and the accumulation of fine dirt in suspension, typical of piston engine operation, do not occur to any significant degree in a turbine engine. Oil service is actually similar to that of automatic transmission lubricant, although less severe due to the absence of any clutch lubricating function and resulting contamination with material worn from the clutch facings. Therefore, a lifetime oil or a no oil change schedule could probably be safely considered, but without more extensive experience, a conservative 24,000 mile change interval is specified.

Air, oil, and fuel filter changes will constitute the major scheduled service requirements. Experience has shown that a one year or 12,000 mile maintenance interval for these filters is adequate. Future operating experience may indicate extended intervals for the oil and fuel filter changes; however, the original service requirement for the air filter appears to be permanent. The air filter elements can be cleaned at the 12,000 mile point, but must be replaced at 24,000 miles.

A reduction in compressor performance can be caused by an accumulation of fine, oily dirt on compressor elements. Compressor cleaning is very simply accomplished by introducing a fine granular sublimating material into the inlet while the engine is running.

A control system check to verify proper engine control and the correct functioning of the engine self-protection features (overspeed, overtemperature, start cycle, etc.) is accomplished with a calibration instrument or test bench. The procedure; however, will be less complicated than that for a piston engine tune-up because no ignition timing is required. Comparative measurements of steady state data will be taken and the required adjustments made

Using the retail prices and the frequency of scheduled maintenance from the Projected Maintenance Schedule for turbine engines, an Engine Related Lifetime Maintenance Cost Estimate, Table 10, was then developed for the automotive turbine engine. As can be seen, a lifetime cost reduction of $60.25 is possible if petroleum base oil at a retail price of $.85 per quart is substituted for the synthetic turbine oil.

TABLE 10. ENGINE RELATED LIFETIME MAINTENANCE COST ESTIMATE
1975 GAS TURBINE POWERED VEHICLE

Based on:
1. Projected Maintenance Schedule
2. 105,000 Total Accumulated Miles
3. 10 Years Total Life (10,500 Miles/Year)

Interval Miles/Months	Lifetime Number Intervals Based on		Estimated Retail Price	Total lifetime Cost
	Miles	Months		
12,000/12	1	10	$18.65	$186.50
24,000/24	-	5	$21.80	$109.00
			Total Engine Related Lifetime Scheduled Maintenance Cost (Using Synthetic Turbine Oil)	$295.50
			Using Petroleum Base Oils at $.85/quart	$235.25

SECTION V

Salvage Value

A cursory review of the material content of any gas turbine engine indicates that a portion of the original cost could be recovered by salvaging a used engine for its material alone. A study of the engine material was then made to estimate the salvage value of the automotive turbine engine.

Using the cost tabulations, Table 1, the engine detail parts were categorized according to material and the total weight for each material was calculated. A salvage price was obtained for each material listed and the total material value was calculated as the product of the material weight and the salvage price. As presented in Table 11, the automotive turbine engine salvage value, based on material content, is approximately $21.40.

It was then necessary to determine if the salvage value represented a recoverable cost after considering the labor required to dismantle the engine and separate the different materials. To aid in this determination, an estimate of disassembly time was made. Experience indicated that one man can completely disassemble the engine in three hours, using a standard work bench and conventional tools. However, this estimate is based on a carefully executed procedure wherein special care is taken to remove all parts without damage. If the salvage operation was set up for high volume disassembly utilizing power tools and special fixtures, the total labor required would be approximately 20 minutes or only $1.50 direct labor cost.

TABLE 11. AUTOMOTIVE TURBINE ENGINE MATERIAL CONTENT AND SALVAGE VALUE.

Material	Weight	Salvage Price per Pound	Value
Aluminum	60 lbs.	$ .10	* $5.40
Hastelloy X	6.8 lbs.	.65	4.30
Inconel 713LC	4.97 lbs.	1.00	4.97
Stainless Steel	38 lbs.	.13	4.94
Alloy Steel	30 lbs.	.03	.90
Stamped Steel	45 lbs.	.02	.90
		Total	$21.41

*Assuming 90% recovery

The current practice when salvaging piston engines is to remove the accessories; such as starters, alternators, etc. after the engine is removed from the vehicle. These items are then either sold as used parts or rebuilt for resale. It is presumed that the same practice would be used for automotive turbine engines.

After removing the accessories, the engine could be placed on a rotateable fixture; which would facilitate the disassembly of the gearbox, compressor diffuser, radiant shield, rear cover plate, and the remainder of the engine from the main housing. The gearbox could then be disassembled to remove the gears, shafts, bushings, and oil line tubing, after which, the gear case could be deoiled.

The burner components, impeller, shafts, nozzles, turbine wheels, and exhaust diffuser would be removed from the engine housing by removing the locking nuts or by utilizing a cutting torch. The inside of the engine housing could then be shot-blasted to remove the insulation material. No salvage estimate was made for the regenerator cores, although it would be possible to crush and regrind the cores to recover the fused silica. Parts would be segregated by material and sheet metal parts could be compressed into bundles.

The salvage value of the automotive turbine engine of $21.40 probably represents a $10.00 advantage over the salvage value of a 465 pound V-8 piston engine consisting mostly of gray iron with a scrap price of $.02 per pound. However, recovering the radiator from the piston engine vehicle would provide an additional $4.68 (18 lbs at $.26/lb), which would reduce the turbine engine salvage advantage to approximately $5.00.

SECTION VI

Net Cost of Ownership Analysis

A cost of ownership analysis based on the results of this study must be approached in relative terms because the study itself uses the piston engine powered vehicle as a basis for cost comparisons. Further, it can safely be assumed that the initial cost of ownership of a turbine powered automobile will differ only as a result of those costs associated with the power plant. The discrete cost elements of vehicle accessories and chassis will remain constant, regardless of the type of engine installed. In addition, maintenance costs will also be the same except as associated with the engine.

The manufacturing cost study produced two estimates for the production of automotive turbine engines, i.e. $219.80 and $172.86. Both of these estimates compare favorably with the estimated direct cost of manufacturing a piston engine at $186.64. However, the latter turbine engine estimate is considered to be the more realistic because it is based on mass production manufacturing processes, which can be available by 1975. It is apparent then that a direct manufacturing cost reduction of approximately $13.00 per engine can be realized through the mass production of automotive turbine engines.

The computer program constructed to estimate the fuel consumption of an automotive turbine engine over a specified velocity-time schedule provided another basis for comparing a turbine engine powered vehicle with a piston engine vehicle. The results of this fuel cost analysis, when compared with the same analysis conducted on a piston engine vehicle over the same driving schedule, indicated that the automotive turbine engine was more economical by approximately 1.5 miles per gallon. The piston engine averaged 16.6 mpg while the turbine engine averaged 18.1 mpg. Extended over the 105,000 mile life of the automobile, this represents a significant savings in fuel cost.

The maintenance cost analysis defined an additional advantage of the turbine engine automobile. The scheduled maintenance costs for both engine types were estimated for the 105,000 mile life of the vehicle, and it was determined that the turbine engine would cost approximately $295 to maintain ($235 using less expensive engine oil) while the piston engine scheduled maintenance cost would be $641. This analysis assumed that overhaul and unscheduled repair costs would be approximately equal.

Table 12 presents these engine costs as a comparative cost of ownership extended over the 105,000 mile life of the engine. The estimated engine retail prices were obtained by factoring the direct manufacturing costs, as follows:

2.0 X Direct Mfg. Cost = Transfer Price
1.2 X Transfer Price = Distributor Price (Sales Division)
1.2 X Distributor Price = Dealer Cost
1.2 X Dealer Cost = Retail Price
∴ Direct Mfg. Cost X 3.47 = Retail Price

TABLE 12. RELATIVE COST OF OWNERSHIP EXTENDED OVER THE LIFE OF THE ENGINE (105,000 MILES)

	Piston Engine*	Turbine Engine	Turbine Engine**
Estimated Engine Retail Price (Calculated from direct mfg. cost)	$ 647.64	$ 762.71	$ 599.82
Fuel Cost @ $.31 per gallon	1,960.90	1,805.37	1,805.37
Scheduled Maintenance Costs	641.45	295.50	***235.25
Total	3,249.99	2,863.58	2,640.44
Engine Salvage Value (Deduct)	14.04	21.41	21.41
Total Engine Cost for 105,000 miles	$3,235.95	$2,842.17	$2,619.03
Lifetime Cost Difference	--	($393.78)	($616.92)

*Piston engine costs are for a 1972 standard V-8 engine and do not include the costs of emission control equipment required to meet the 1976 Federal Standards.

**Target price of basic engine based on processes development

***Using petroleum base engine oil

SECTION VII

Development Program Plan

Based on the results of this economic analysis and the technology acquired by Williams Research during the design, development, and installation of a turbine engine into a production automobile; those areas requiring further development effort have been defined. While technical demonstration of the 1975 baseline preproduction engine can be assured because of existing technology, the successful completion of this development program will ensure that the manufacturing costs will be competitive with those of the piston engine.

As discussed elsewhere in this report, changes to engine accessories, vehicle system accessories, and the vehicle body and frame are either minimal or not required. In addition, most items discussed as producibility changes to the basic engine do not represent any significant problem to existing manufacturing process technology. It was concluded; however, that a significant reduction in manufacturing cost could be realized through process development in four major areas. These areas are:

a. Permanent mold centrifugal casting for the aluminum compressor rotor

b. Alternate casting process for the turbine wheels.

c. Powder metal gears for the reduction gearbox.

d. Aluminum die casting for the main engine housing.

A conservative approach has been used for each of these areas in order that feasibility can be proven before proceeding further with the development effort.

Permanent Mold Centrifugal Casting

The presently available aluminum compressor rotors are cast by a lost wax or rubber mold process, and vendor quoted prices range from \$12.00 to \$15.00 each at the 1,000,000 per year production rate. However, the material content of each rotor is less than two pounds and is worth less than \$.50.

Recent studies have shown that these castings could be made by a segmented permanent mold process. The segments would be radially inserted in T-slots, and the mold mounted on a spin table. The blades would be formed by filling the spaces between the segments with aluminum, the metal flow being controlled by the centrifugal action of the spin table. The blades could then be press-formed, if necessary, to provide the proper lead angle for the inducer section. Using this method, a $1.50 compressor rotor could be produced at the required production rate. Table 13 outlines the suggested development effort for this process.

Turbine Wheel Casting Processes

The quoted price for turbine wheels at the production rate of 1,000,000 parts per year is approximately $40.00 each. The lost wax investment casting process is used and again results in a casting price that is not consistent with the value of the material, which is approximately $3.00 per part. A significant cost reduction can be realized in the manufacturing cost element of the automotive turbine engine if an alternate process can be developed.

There are at least three basic concepts that show promise of being feasible and; therefore, justify investigation. These concepts are:

a. Segmented Core Concept

b. Coated Pattern Concept

c. Insert Cast Blade Concept

The logical approach would be to initially investigate each concept simultaneously along with several variations until it could be determined which concept offered the greatest feasibility and cost reduction potential. At this time, development would continue with one concept while phasing out the remaining efforts.

While a detailed definition of the total program requirements and schedule cannot be made at this time, a gross estimate is as follows:

a.	Capital Equipment:	$100,000
b.	Tooling:	$ 40,000
c.	Materials:	$ 10,000
d.	Labor:	$240,000
e.	Space:	1,600 sq. ft.
f.	Project time:	18 months

TABLE 13. PROGRAM PLAN FOR PERMANENT MOLD CENTRIFUGAL CASTING OF COMPRESSOR ROTORS

Development Effort	Cost
1. Redesign Compressor Rotor	$ 1,600
2. Design Permanent Mold	$ 4,000
3. Produce Mold	$ 12,000
4. Refine Mold	$ 8,000
5. Pour Preliminary Castings	$ 3,200
6. Evaluate Surface Finish, Dimensional Characteristics, etc.	$ 3,200
7. Develop Mold Wash	$ 4,000
8. Develop Casting Techniques	$ 80,000
a. Optimum Mold Preheat Temperature	
b. Optimum RPM for spin table	
c. Pouring Temperature and Rate	
d. Alloy Selection	
e. Proper Heat Treat	
9. Functional Testing of Rotors	$ 20,000
Total Labor Cost	$150,400
10. Equipment Requirements	
a. Small Melting Furnace	$ 8,000
b. Spin Table	$ 3,000
c. Miscellaneous Small Tools and Gages	$ 100
11. Material Cost (Aluminum Ingot. Mold Wash, etc.)	$ 500
Estimated Total Program Cost	$161,500
Estimated Program Duration - 12 months	

Powder Metal Techniques

The use of powdered metal for the reduction and accessory gears in the turbine engine gearbox offers a potential material and manufacturing cost reduction of 20% to 30% when compared with the present machining costs associated with steel gears.

The general approach to developing the powder metal gear set would be to first establish the quality required for each of the nine gears in the gearbox. Two basic types of gears would be considered:

a. Conventional powder metal gears where the powdered metal is pressed and sintered to produce gears of approximately 85% density.

b. Reforged gears where the process is to reheat the sintered gears to forging temperature and repress to obtain approximately 99% density.

An outline of the development program to produce powdered metal gears for the turbine engine gearbox is presented in Table 14. To reduce program risk, one gear set at a time is substituted in a conventional gearbox and its performance is verified before fabricating the next powder metal gear set. As each gear set is developed, the finishing operations will be minimized to provide the lowest cost possible consistent with the functional requirements of each gear.

Aluminum Die Casting

While the development of an aluminum die cast main housing would not result in a significant manufacturing cost reduction, the use of aluminum instead of ductile iron would represent a considerable reduction in engine weight, with the attendant advantage of enhancing the power-to-weight ratio of the engine. The ductile iron housing used on the basic turbine engine weighs approximately 120 pounds, whereas a comparable aluminum housing would weigh between 30 and 35 pounds. A reduction in the weight of the engine required to power the vehicle results in many indirect and somewhat obscure advantages from both performance and cost standpoints. For example, as the power-to-weight ratio is increased, fuel costs and performance benefits are realized. In addition, engine weight directly effects vehicle systems and structures; such as, tire loading, brake requirements, and mounting provisions; which in turn have an effect on vehicle cost. The development program to provide an aluminum engine housing is outlined in Table 15. This program is based on the assumption that existing vendor supplied casting equipment will be utilized.

TABLE 14. PROGRAM PLAN FOR POWDER METAL GEARS

Activity	Approx. Cost
1. Redesign gear train and case	$ 4,000
2. Evaluate gear parameters to establish strength requirements, material, and tentative powder metal process, etc.	$ 4,000
3. Acquire noise level instrumentation and raw materials, etc.	$ 20,000
4. Modify powder metal press for helical gear production (rotating punch holder)	$ 50,000
5. Build two complete gearboxes incorporating machined steel gears. Test for noise level, endurance, etc.	$ 40,000
6. Design and build powder metal tooling for one gear set determined to have lightest load requirement. Fabricate gears and substitute in gearbox; evaluate performance.	$ 50,000
7. Fabricate and substitute gears (one set at a time) as in (6) until the gear loading requirements exceed the capability of conventional powder metal helical gears. Thereafter, design and build tooling for reforging process, fabricate and substitute gears until the set is completed or the capability of the reforged gears is exceeded.	$ 450,000
8. Evaluate program and hardware to verify performance, reliability, durability, etc. Build tooling for volume production.	$ 300,000
Estimated Total Program Cost	$ 918,000
Estimated Program Duration - 36 months	

TABLE 15. PROGRAM PLAN FOR ALUMINUM DIE CAST ENGINE HOUSING

Activity	Approx. Cost
1. Acquire aluminum sand castings from existing ductile iron pattern tooling. Insulate housing with present materials and techniques.	$ 4,000
2. Fabricate complete engine and subject to normal operating cycle. Record temperature data, and evaluate strength, expansion, and warpage problems.	$ 10,000
3. Investigate alternate insulation materials and techniques	$ 6,000
4. Redesign housing for extraction of metal cores and permanent mold casting.	$ 4,000
5. Design permanent mold	$ 4,000
6. Build permanent mold	$ 8,000 Matl. $ 1,000
7. Pour castings, develop casting techniques, adjust mold design, evaluate castings.	$ 20,000
8. Evaluate permanent mold vs. die casting process, considering equipment cost, cyclic rates, yield, casting strength, suitable alloys and their costs, etc.	$ 10,000
9. If die casting is justified, design suitable die.	$ 10,000
10. Build die	$ 60,000 Matl. $ 6,000
11. Evaluate and develop die	$ 60,000
Estimated Total Program Cost	$ 193,000
Estimated Program Duration - 36 months	

References

1. U. S. Department of Health, Education, and Welfare: Urban Dynamometer Driving Schedule. Federal Register, Vol. 35, No. 219, November 10, 1970.

2. U. S. Environmental Protection Agency: Prototype Vehicle Performance Specification, January 3, 1972.

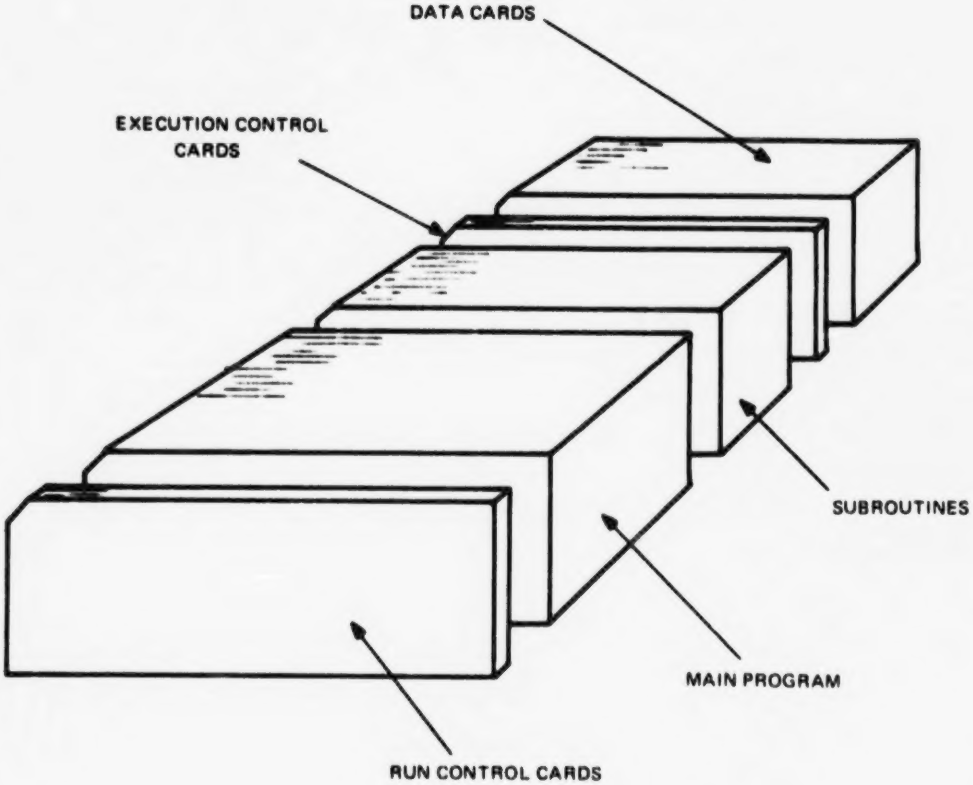
3. J. J. Taborek: Machine Design, Mechanics of Vehicles, 1957.

4. Cope, E. M., and C. L. Gauthier: Cost of Operating an Automobile. U. S. Department of Transportation Report, February 1970.

APPENDIX I

FUEL CONSUMPTION PROGRAM LISTING

PROGRAM STACKING SEQUENCE


DATA CARDS
EXECUTION CONTROL CARDS
SUBROUTINES
MAIN PROGRAM
RUN CONTROL CARDS

NOTE: THE RUN CONTROL AND EXECUTION CONTROL CARDS SHOWN IN THE PROGRAM LISTING ARE FOR THE COMPUTER SCIENCES CORPORATION CRJE DATA SYSTEM

DATA INPUT INSTRUCTIONS FOR GAS TURBINE

Note: All data is accepted in a free field format.

DATA CARD NO.	VARIABLES
1	PA, TA, W, RDIF, RG(1), RG(2), RG(3), RGENG
2	EDIF, EG(1), EG(2), EG(3), HPDES, WFDES, S2DES, FSW
3	IWST, IDWL, DDW, DLR, DL, H, F, AMU, CDAF
4	IAC, DWI, PTI, TCI, FLHV, TMAX, DT, CMAX, LOPT
5	TKFO(I), TCSRO(I), TCTRO(I), I = 1, 29
6	V(1), V(2), V(3), V(4), V(5), V(6), V(7), V(8), V(9), V(10)
(6+CMAX)	V(TMAX-8), ... , V(TMAX-1), V(TMAX), V(TMAX+1)
7	SS1(I), PRBA(I), I = 1, 11
8	S2 (I), TBI(I, J), I = 1, 9; J = 1, 6
9	SS1(I), WBF(I), I = 1, 11

DATA INPUT INSTRUCTIONS FOR I. C. ENGINE

DATA CARD NO.	VARIABLES
1	PA, TA, W, RDIF, RG(1), RG(2), RG(3), RGENG
2	EDIF, EG(1), EG(2), EG(3), HPDES, WFDES, S2DES, FSW
3	IWST, IDWL, DDW, DLR, DL, H, F, AMU, CDAF
4	IAC, DWI, PTI, TCI, FLHV, TMAX, DT, CMAX, LOPT
5	TKFO(I), TCSRO(I), TCTRO(I), I = 1, 29
6	V(1), V(2), V(3), V(4), V(5), V(6), V(7), V(8), V(9), V(10)
(6+CMAX)	V(TMAX-8), ... V, (TMAX-1), V(TMAX), V(TMAX+1)
7	S2(I), HP(I, J), I = 1, 17, J = 1, 9
8	S2(I), FF(I, J), I = 1, 17, J = 1, 9

INPUT VARIABLE DEFINITIONS:

Symbol	Type	Units	Explanation
PA	Real	Psia	Ambient Pressure
TA	Real	°R	Ambient Temperature
W	Real	Lb	Total Vehicle Weight
RDIF	Real	—	Differential Speed Ratio
RG(1)	Real	—	Transmission 1st Speed Ratio
RG(2)	Real	—	Transmission 2nd Speed Ratio
RG(3)	Real	—	Transmission 3rd Speed Ratio
RGENG	Real	—	Power Turbine to Torque Converter Speed Ratio
EDIF	Real	—	Differential Mechanical Efficiency
EG(1)	Real		Transmission 1st Speed Mech. Efficiency
EG(2)	Real		Transmission 2nd Speed Mech. Efficiency
EG(3)	Real		Transmission 3rd Speed Mech. Efficiency
HPDES	Real	HP	Engine Design Power (Standard Day Conditions)
WFDES	Real	lb/hr	Engine Design Fuel Flow (Standard Day Conditions)
S2DES	Real	RPM	Engine Design (Standard Day Conditions)
FSW	Real	lb/gal.	Fuel Specific Weight
*IWST	Integer	—	I/O = Standard/Input Values of DLR, DL, H, F, AMU
IDWL	Integer	—	1/2/3 = Front/Rear/All 4 Wheels being driven
DDW	Real	In.	Drive Wheel Diameter
DLR	Real	In.	Vehicle CG. Distance from Rear Axle
DL	Real	In.	Vehicle Wheelbase
H	Real	In.	Height of Vehicle CG. above Ground
F	Real	—	Tire Rolling Resistance Coefficient
AMU	Real	—	Friction Coefficient-Tire to Road
CDAF	Real	Ft.^{2}	Vehicle Drag Coefficient x Frontal Area
IAC	Integer	—	0/1 = Airconditioning Power Load Off/On
DWI	Real	In-Lb-Sec^2	Wheels, Total Polar Moment of Inertia
PTI	Real	In-Lb-Sec^2	Power Turbine (I.C. Engine) Polar Moment of Inertia
TCI	Real	In-Lb-Sec^2	Torque Converter Polar Moment of Inertia
FLHV	Real	BTU/Lb	Fuel Lower Heating Value
TMAX	Real	Sec.	Maximum Time for Input Velocity Schedule
DT	Real	Sec.	Time Increment between Velocities
CMAX	Real	—	Number of Cards in Velocity Schedule
LOPT	Integer	—	0/1 = Short/Long Output Option
TITLE	—	—	Driving Cycle Identification (up to 72 characters)

INPUT VARIABLES DEFINITIONS (Continued)

Symbol	Type	Units	Explanation
V(N)	Real	MPH	Vehicle Velocities, 10 per Card, CMAX Cards
TKFO	Real	RPM $\sqrt{\text{LB-FT}}$	Torque converter K factor-out
TCSRO	Real	—	Torque converter speed ratio
TCTRO	Real	—	Torque converter torque ratio
SS1	Real	—	% Gas generator speed
PRBA	Real	—	Pressure ratio (Pressure at inlet to the burner to the ambient pressure)
S2	Real	—	% Power turbine (I.C. Engine) speed
TBI	Real	R	Burner inlet temperature
WBI	Real	LB/SEC	Mass rate of air flow
HP	Real	—	% Horse power
FF	Real	—	% Fuel flow

*IWST = 0 - Any input values of DLR, DL, H, F & AMU are ignored by program and the following values for a typical sedan are assumed:

F = 0.02
AMU = 0.8
W(1) = 0.357
W(2) = 0.755
W(3) = 1.0

Where W(1, 2, 3) is the weight transfer factor for the drive wheel location indicated. This factor is normally calculated from DLR, DL & H.

IWST = 1 - Program accepts input values for DLR, DL, H, F, AMU

OUTPUT VARIABLE DEFINITIONS: (Long Form)

Symbol	Units	Explanation
TIME	sec.	Accumulated Time
AVE. V	Mph.	Average Velocity Over Time Increment DT
GEAR	—	Automatic Transmission Speed Used During DT
TCSR	—	Torque Converter Speed Ratio During DT
HPRL	HP	Average Road Load Power Required During DT
HPAC	HP	Average Acceleration Power Required During DT
HPAS	HP	Average Accessory Power Required During DT
HPTOT	HP	Total Average Engine Power Required During DT (Includes mechanical efficiency of drive train)
S2A	%	Average Power Turbine Speed During DT
SFC	—	Engine Average Specific Fuel Consumption During DT
PBI	PSIA	Total burner inlet pressure
TBIA	°R	Burner inlet temperature
WBIA	LB/SEC	Mass rate of air flow
WF	LB/HR	Mass rate of fuel flow
TBE	°R	Burner exit temperature
S1A	%	Gas generator speed

AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION PROGRAM

```
AGTFCP,NM-REL/LIB$  CREATE:12/07/72 TIME:07:34:00 FREQ:7 SIZE:4 KIND:DISK LIFE:
PERM ACCESS:REPL
1L
    20      C
    30      C      EPA, AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION PROG.
    40      C                         (A.G.T.F.C.P.)
    50      C
    60      C                              MAIN
    70      C
    80              COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
    90             1S1(9),WFO(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
   100             2DL,DLR,H,IWST,N,EM,ICSR,TCT,WFI,WI(3),PTI,S5,S4,S2MAX,S2A,HPAS,
   110             3TKF,TCTR,HPP,S1MAX,WFDES,S1A,WF,C,XXS2,S2DES,DHP,DELHP,VM,FSW,J,
   120             4IDWL,A,AMAX,RGENG,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
   121              DIMENSION TITLE(18),TKFO(30),TCSRO(30),TCTRO(30)
   122              DIMENSION SS1(11),PRHA(11),S2(6),TBI(6,9),TBII(9),WBI(11)
   125              CALL OPEN('!EQUATE 1 IN$:EQUATE 2 OUT$',7)
   126              CALL SETIH(1,-1)
   130              READ(1,91) PA,TA,W,RDIF,RG(1),RG(2),RG(3),RGENG
   131              READ(1,91) EDIF,EG(1),EG(2),EG(3),HPDES,WFDES,S2DES,FSW
   140              READ(1,91) IWST,IDWL,DDW,DLR,DL,H,F,AMU,CDAF
   141              READ(1,91) IAC,DWI,PTI,TCI,FLHV,TMAX,DT,CMAX,LOPT
   141.1            DO 1 II=1,24
   141.2            READ 91,TKFO(II),TCSRO(II),TCTRO(II)
   141.3          1 CONTINUE
   142              RIAC=IAC
   143              RIWST=IWST
   144              RIDWL=IDWL
   145              PRINT 262
   146              PRINT 270
   147              READ(1,10)TITLE
   148           10 FORMAT (18A4)
   149              RLOPT=LOPT
   150              PRINT 30
   151              WRITE(2,91)PA,TA,W,HPDES,WFDES,S2DES
   152              PRINT 35
   153              PRINT 31
   154              WRITE(2,91)RIWST,RIDWL,RIAC,RLOPT,FLHV,FSW
   155              PRINT 36
   156              PRINT 32
   157              WRITE(2,91)RDIF,RG(1),RG(2),RG(3),RGENG,CDAF
   158              PRINT 35
   159              PRINT 33
   160              WRITE(2,91)EDIF,EG(1),EG(2),EG(3),DDW,DLR
   161              PRINT 35
   162              PRINT 34
   163              WRITE(2,91)DL,H,F,AMU,PTI,TCI
   164              PRINT 36
   165              PRINT 35
   166              WRITE(2,91)DWI,TMAX,DT,CMAX
   167              PRINT 36
   168           30 FORMAT(4X,'PA',12X,'TA',11X,'W',10X,'HPDES',8X,'WFDES',8X,'S2DES')
   169           31 FORMAT(3X,'IWST',10X,'IDWL',9X,'IAC',9X,'LOPT',9X,'FLHV',10X,'FSW'
   170             1)
```

3

```
171         32 FORMAT(3X,'MODE',9X,'RG(1)',8X,'RG(2)',8X,'RG(3)',8X,'RGENG',9X,'C
172           1OMF')
173         33 FORMAT(3X,'MODE',9X,'EG(1)',8X,'EG(2)',8X,'EG(3)',9X,'DDW',10X,'DL
174           1W')
175         34 FORMAT(4X,'V',12X,'H',12X,'F',11X,'AMU',10X,'PTI',10X,'TCI')
176         35 FORMAT(4X,'DI',10X,'TMAX',10X,'DI',9X,'CMAX')
177         36 FORMAT(1H0)
178            II=CMAX
179            N=0
179.1          LL=1
180            DO 90 I=1,II
190            READ (1,91) (V(N+K),K=1,10)
200         93 N=N+10
210         90 CONTINUE
220            N = 1
230            J = 1
240            FM = 1.0
250            TCSW = 1.0
270            T=DT
280            DIST = 0.
300            WFI = 0.
310            VA=45.
320            FTC = 1.0
321            CALL VMAXX
322            IF(IOPT.GT.3) GO TO 20
330            PRINT 264
333            GO TO 21
334         20 PRINT 265
335            PRINT 406
336            PRINT 407
337         21 CONTINUE
340        100 VA(N) = (V(N)+V(N+1))/2.
343        201 V3=VA(N)
344            I=2
345            K=2
350            DDIST = VA(N)* T/3600.
360            S5 = 336.21*VA(N)/DDW
370            S4 = ROIF*S5
380            S3(1) = RG(1)*S4
390            S3(2) = RG(2)*S4
400            S3(3) = RG(3)*S4
410            S2 = RGENG*S3(J)
420            S3AA(1) = S3(J)
430            S2AA(1)=S3(J)
431        202 IF(VA(N).GT.0.) GO TO 350
432            S2=0.
433            HP=0.
434            GO TO 257
435        350 CONTINUE
440            FD = .00232*CDWF*PA*VA(N)**2./TA
450            FR = (W/55.)*(1.+.0021*VA(N)+.000026*VA(N)**2.)
460            HPW = (FD+FR)*VA(N)/375.
470        133 C = V(N+1)-V(N)
480            IF (C.LT.0.) GO TO 131
```

```
490     119 FZ = 1.+(15+5.5/(A*10)**2.))*(0/T+TI*(S2A/S5)+TCI*(S3(J)/S5))
500         HPAC = FZ*R*(V(N+1)**2.-V(N)**2.)/(HS3+1.0*DT)
510         GO TO 120
520     131 HPAC = 0.
530     120 HP = (HPW+HPAC)/(EFF(J)*EC(IP*TC))
540     203 IF (IAC.LE.2) GO TO 127
550         HPX=HPDES-15.0
560         GO TO 128
570     127 HPX=HPDES-5.0
580     128 S2SHFT = S2DES*1.2346
590         S3SHFT = S2SHFT/[illegible]
600         CALL [illegible]
610         S3AA(K) = S3(J)
620     204 ER3 = ABS(S3AA(K)-S3AA(K-1))/S3AA(K)
630         IF (ER3.LE.0.01) GO TO 200
631         IF(K.GE.5) GO TO 25
640         K = K+1
650         GO TO 133
651      25 PRINT 26
652      26 FORMAT(1X,*GEAR SHIFT LOOP LIMIT REACHED*,/)
660     200 S3J = S3(J)
661         CONT=1.
662     220 CONTINUE
670         TO3=HP*5250./S3A
671         TRF=S3A/TC*R*.5
672         DO 361 II=1,24
673         IF(TRF-TRFO(II))362,362,361
674     361 CONTINUE
675     362 RATIO=(TRF-TRFO(II-1))/(TRFO(II)-TRFO(II-1))
676         TCSR=TCSRO(II-1)+RATIO*(TCSRO(II)-TCSRO(II-1))
681         TCTR=TCTRO(II-1)+RATIO*(TCTRO(II)-TCTRO(II-1))
682         S22A=S3A/TCSR
683         TI=TO3/TCTR
740     251 S2AA(I)=S22A*RG(IG)
790     205 ER2 = ABS(S2AA(I)-S2AA(I-1))/S2AA(I-1)
800         IF (ER2.LE.0.02) GO TO 253
801         IF(I.GE.10) GO TO 29
810         S2A = S2AA(I)
820         I = I+1
830         GO TO 133
831      29 PRINT 37
832      37 FORMAT(1X,*S2 SPEED LOOP LIMIT REACHED*,/)
840     253 C = V(N)-V(N+1)
850         IF (C.GT.0.) GO TO 257
860         CALL WLSPIN
870         C = A-AMAX
880         IF (C.LE.0.) GO TO 257
890         PRINT 258,T
900         PRINT 259,V3
910         PRINT 260,A
920         PRINT 261,AMAX
921     257 CONTINUE
930         CALL ACCESH
940         HPW = HPW+HPAS
```

```
      CALL ENGINE(THETA,DELTA)
      IF(L-1)1005,995,1005
  995 READ 1000,(SS1(L),GAMMA(L),L=1,11)
 1000 FORMAT( )
 1005 M=.05
      L=2
 1110 IF(S1A-SS1(L))1120,1130,1140
 1140 L=L+1
      IF(L-11)1110,1110,1150
 1130 GAMMAA=GAMMA(L)
      GOTO 1150
 1120 GAMMAA=GAMMA(L-1)+(GAMMA(L)-GAMMA(L-1))*(S1A-SS1(L-1))/(SS1(L)-SS1
     1(L-1))
 1150 IF(L-1)1160,1155,1160
 1155 READ 1000,((S2(L),THI(L,II),L=1,6),II=1,9)
 1160 M=.2
      L=2
      II=1
 1210 IF(S2A-S2(L))1220,1230,1240
 1240 L=L+1
      IF(L-6)1210,1210,1250
 1230 THII(II)=THI(L,II)
      GOTO 1250
 1220 THII(II)=THI(L-1,II)+(THI(L,II)-THI(L-1,II))*(S2A-S2(L-1))/(S
     12(L)-S2(L-1))
 1250 L=2
      II=II+1
      IF(II-9)1210,1210,1270
 1270 S1(1)=0.500
      S1(2)=0.510
      S1(3)=0.634
      S1(4)=0.704
      S1(5)=0.764
      S1(6)=0.850
      S1(7)=0.924
      S1(8)=.960
      S1(9)=1.000
      L=2
 1271 IF (S1A-S1(L))1280,1290,1300
 1300 L=L+1
      IF(L-9)1271,1271,1310
 1290 THTA=THII(L)
      GOTO 1310
 1280 THTA=THII(L-1)+(THII(L)-THII(L-1))*(S1A-S1(L-1))/(S1(L)-S1(L-1
     1))
 1310 IF(L-1)1302,1301,1302
 1301 READ 1000,(SS1(L),[illegible](L),L=1,11)
 1302 M=0.05
      L=2
 1315 IF(S1A-SS1(L))1320,1330,1340
 1340 L=L+1
      IF(L-11)1315,1315,1350
 1330 [illegible]=[illegible](L)
      GOTO 1350
 1320 WBIA=WBI(L-1)+(WBI(L)-WBI(L-1))*(S1A-SS1(L-1))/(SS1(L)-SS1(L
     1-1))
 1350 WF=WF*(THETA)**0.5*DELTA
      LL=2
      WF=WF*WFOFS
      IF(WF-.)2,3,3
    2 WF=0.
    3 PBI=PR-AA*PA*DELTA
      TBIA=TBIA*THETA
      S1A=S1A*THETA**0.5
      S2A=S2A*THETA**0.5
      WBIA=WBIA*DELTA/THETA**0.5
      Y=(WF/(WHTA*3600.))/(1.+.000157*(THIA-1200.))
      T4=TBIA+(-.1342+((.1342)**2.+4.*.1375*Y)**.5)*10000./(2.*.1375)
      SFC=WF/HPR
      WFT = WFT+WF
      DIST = DIST+DDIST
      N = N+1
      IF(LOPT.GT.0) GO TO 81
      GO TO 82
   81 PRINT 305,T,V3,J,TCSR,HPRL,HPAC,HPAS,HPR,S2A,SFC,PBI,TBIA,WBIA,
     1WF,THE,S1A
   82 CONTINUE
      IF (TMAX.GT.T) GO TO 299
      IF(TMAX.LE.T) GO TO 300
  299 CONTINUE
      T=T+DT
      GO TO 100
  300 WFTG = (WFT*DT/3600.)*(18700./FLHV)*1./FSW
      WFC = WFTG*0.3]
      APMG = DIST/WFTG
      ABTUPM = (FSW/APMG)*FLHV
      PRINT 271,TITLE
      PRINT 272,WFTG
      PRINT 273,DIST
      PRINT 274,WFC
      PRINT 275,APMG
      PRINT 276,ABTUPM
      PRINT 278,VMAX
      PRINT 279,S2MAX
      GO TO 301
   91 FORMAT ( )
  305 FORMAT(2X,F7.1,1X,F6.1,3X,I2,2X,F6.3,2X,F6.1,2X,F6.1,2X,F6.1,2X,F6
     1.1,2X,F5.3,2X,F5.3,2X,F5.2,2X,F7.2,2X,F5.3,2X,F6.3,2X,F7.2,2X,F5.3
     2,)
  306 FORMAT(4X,'TIME  AVE. V  GEAR  TCSR    HPRL    HPAC    HPAS    HPT
     1OT     S2A',4X,'SFC   PBI   TBIA    WHIA    WF       THE    S1A',
     2)
  307 FORMAT (5X,'(SEC)   (MPH)',45X,'(PERCENT)',//)
  256 FORMAT (4X,'WHEEL SPIN AT T =',F10.2,' SEC.'/)
  259 FORMAT (10X,'V =',F10.2,' MPH.'/)
  260 FORMAT (18X,'A =',F10.2,' FT/SEC**2'/)
  261 FORMAT (15X,'AMAX = ',F10.2,' FT/SEC**2',/)
  262 FORMAT (10X,'AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION
1290             1 PROGRAM',///)
1320         270 FORMAT (4X,'INPUT DATA',//)
1370         266 FORMAT(4X,'PROGRAM OUTPUT - LONG FORM',///)
1400         269 FORMAT(4X,'PROGRAM OUTPUT - SHORT FORM',///)
1410         271 FORMAT (4X,//,'     DRIVING CYCLE = ',1X,A4,//)
1420         272 FORMAT (4X,'TOTAL FUEL USED                    =',F10.4,' GALLONS',//)
1430         274 FORMAT (4X,'TOTAL FUEL COST (.21/GAL.)         =',F10.4,' DOLLARS',//)
1440         273 FORMAT (4X, 'TOTAL DISTANCE TRAVELED            =',F10.4,' MILES',//)
1450         275 FORMAT (4X,'AVERAGE M.P.G.                     =',F10.4,//)
1460         276 FORMAT (4X,'AVERAGE BTU/MILE                   =',F10.4,//)
1470         278 FORMAT (4X,'MAXIMUM STEADY STATE VELOCITY  = ',F6.2,' M.P.H.',//)
1480         279 FORMAT (4X,'POWER TURBINE SPEED AT VMAX    = ',F5.2,' PERCENT',///)
1490         301 CONTINUE
1500             END
10
```

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```
ENGINE.GT-REL/LIB$  CREATE:12/04/72 TIME:08:24:33 FREQ:8 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
ILIST
            SUBROUTINE ENGINE(THETA,DELTA)
      C
      C     CALCS. FUEL FROM H.P. REQUIRED AND POWER TURBINE SPEED
      C
            COMMON V(1380),WG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
           1S1(9),WFO(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
           2DL,DLR,M,IWST,N,FM,TCSR,T,K,WFT,WT(3),PT1,S5,S4,S2MAX,S2A,HPAS,
           3TKF,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DMP,DELHP,VM,FSW,J,
           4IDWL,A,AMAX,RGENG,DLRTC1,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
       1000 FORMAT ( )
            THETA=TA/519.
            DELTA=PA/14.69
            S2A=S2A/THETA**0.5
            HPR=HPR/(DELTA*THETA**0.5)
            S2A = S2A/S2DES
            HPR = HPR/HPDES
        100 HPO(1)=.057*(2.-S2A/.5)*(S2A/.5)
            HPO(2)=.095*(2.-S2A/.55)*(S2A/.55)
            HPO(3)=.205*(2.-S2A/.66)*(S2A/.66)
            HPO(4)=.305*(2.-S2A/.74)*(S2A/.74)
            HPO(5)=.402*(2.-S2A/.79)*(S2A/.79)
            HPO(6)=.605*(2.-S2A/.88)*(S2A/.88)
            HPO(7)=.8*(2.-S2A/.96)*(S2A/.96)
            HPO(8)=.93*(2.-S2A/.98)*(S2A/.98)
            HPO(9)=.99*(2.-S2A/1.)*(S2A/1.)
            S1(1)=.47
            S1(2)=.516
            S1(3)=.634
            S1(4)=.708
            S1(5)=.764
            S1(6)=.856
            S1(7)=.928
            S1(8)=.96
            S1(9)=1.
            M=1
            C=HPR-HPO(M)
            IF(C.LT.0.)GOTO 270
            IF(C.GT.0.)GOTO 272
            GOTO 271
        270 HPR=HPO(1)
        271 S1A=S1(1)
            GOTO 276
        272 M=M+1
            C=HPR-HPO(M)
            IF(C.GT.0.)GOTO 274
            IF(C.LT.0.)GOTO 273
            S1A=S1(M)
            GOTO 276
        273 DMP=(HPR-HPO(M-1))/(HPO(M)-HPO(M-1))
            S1A=S1(M-1)+DMP*(S1(M)-S1(M-1))
            GOTO 276
```

```
2400          274 IF(M.LE.9)GOTO 272
2410              DELHP=(HPR-HPO(9))*100.
2420              HPR=HPO(9)
2430              S1A=S1(9)
2440              PRINT 261,DELHP
2450          276 WFO(1)=.095
2460              WFO(2)=.1115+.09417*S2A-.09167*S2A**2.
2470              WFO(3)=.182+.1398*S2A-.1019*S2A**2.
2480              WFO(4)=.2498+.195*S2A-.1278*S2A**2.
2490              WFO(5)=.3045+.2507*S2A-.1532*S2A**2.
2500              WFO(6)=.402+.4299*S2A-.2379*S2A**2.
2510              WFO(7)=.49+.57*S2A-.2917*S2A**2.
2520              WFO(8)=.6+.55*S2A-.2813*S2A**2.
2530              WFO(9)=.624+.77*S2A-.3875*S2A**2.
2540              M=1
2550              C=S1A-S1(M)
2560              IF(C.LE.0.)GOTO 278
2570          279 M=M+1
2580              C=S1A-S1(M)
2590              IF(C.GT.0.)GOTO 279
2600              IF(C.LT.0.)GOTO 280
2610              WF=WFO(M)
2620              GOTO 281
2630          278 WF=WFO(1)
2640              GOTO 281
2650          280 WF=WFO(M-1)+DHP *(WFO(M)-WFO(M-1))
2655              HPR=HPR*DELTA*THETA**0.5
2660          281 HPR = HPR*HPDES
2670          251 FORMAT (9F6.5)
2680          261 FORMAT (1X,'  REQUIRED H.P. EXCEEDS MAX.HP. BY ',F7.2,2X,'PERCENT'
2690             1,/10X,'HP. REQUIRED SET TO EQUAL MAX.HP. ',//)
2700              RETURN
2710              END
 1QUIT
```

```
VMAXX.GT-REL/LIB»  CREATE:12/04/72 TIME:09:01:43 FREQ:9 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
1LIST
 1510            SUBROUTINE VMAXX
 1520      C
 1530      C     CALCULATES MAX VEHICLE VELOCITY
 1540      C
 1550            COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
 1560           1S1(9),WFO(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 1570           2DL,DLM,M,I,ST,N,FM,ICSM,T,K,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
 1580           3TKF,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
 1590           4IDWL,A,AMAX,RGENG,DLRICI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
 1600            VMAX = VM
 1610        130 S2MAX = (RGENG*RG(3)*RDIF*336.21*VMAX/DDW)/S2DES
 1630            CALL ACCESP
 1640            HP =0.99*(2.-S2MAX/1.0)*(S2MAX/1.0)*HPDES
 1650            HPMAX = EDIF*EG(3)*.95*HP-HPAS
 1660            FDM =.09029*CDAF*PA*VMAX**2./TA
 1670            FRM = (W/65.)*(1.0+.0021*VMAX+.000026*(VMAX**2.))
 1680            VMAX1= HPMAX*374.9/(FDM+FRM)
 1690            ERV = ABS(VMAX1-VMAX)/VMAX
 1700            IF (ERV.LE.0.005) GO TO 131
 1710            VMAX = VMAX+0.4*(VMAX1-VMAX)
 1720            GO TO 130
 1730        131 S2MAX=S2MAX*100.
 1740            RETURN
 1750            END
1QUIT
```

```
ACCESP.GT-REL/LIB$  CREATE:12/04/72 TIME:08:25:31 FREQ:11 SIZE:1 KIND:DISK LIFE:????
PERM ACCESS:REPL
1LIST
 3200           SUBROUTINE ACCESP
 3210     C
 3220     C     ACCESSORY H.P. VS. POWER TURB. SPEED
 3230     C
 3240           COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
 3250          1S1(9),WFO(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 3260          2DL,DLR,M,IWST,N,FM,TCSR,T,K,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
 3270          3TKF,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
 3280          4IDWL,A,AMAX,RGENG,DLRTC1,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
 3281           IF(IAC.GT.0) GO TO 400
 3282           S2AMIN=.0972*S2DES
 3283           GO TO 401
 3284       400 S2AMIN=.227*S2DES
 3285       401 IF(S2A.GT.S2AMIN) GO TO 403
 3286           S2A=S2AMIN
 3287       403 CONTINUE
 3290           S2 = S2A
 3300           IF (S2.LE.S2DES) GO TO 259
 3310           S2 = S2DES
 3320       259 IF (IAC.GE.1) GO TO 261
 3330           HPAS = ((3./(S2DES-S2AMIN))*(S2-S2AMIN)+2.)
 3340           GO TO 262
 3350       261 HPAS = ((11./(S2DES-S2AMIN))*(S2-S2AMIN)+4.0)
 3360       262 RETURN
 3370           END
1QUIT
```

```
GEAR.GT-REL/LIB$  CREATE:12/04/72 TIME:08:25:42 FREQ:11 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
ILIST
            SUBROUTINE GEAR
      C
      C     SELECTS GEAR BOX RATIO REQUIRED
      C
            COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
           1S1(9),WFO(9),DUM,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
           2DL,DLR,H,I,ST,G,FM,TCSH,T,K,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
           3TRF,TLTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
           4IDEL,A,AMAX,RGENG,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
            HPRR = HPAC/HPX
            IF (HPRR.LE.0.95) GO TO 140
            HPRR = .95
        140 S3S = (.3959+1.2916*HPRR-.7069*HPRR**2.)*S3SHFT
            IF (S3(1).GE.S3S) GO TO 144
            J = 1
            GO TO 147
        144 IF (S3(2).GE.S3S) GO TO 146
            J = 2
            GO TO 147
        146 J=3
        147 CONTINUE
            RETURN
            END
IQUIT
```

```
WLSPIN.GT-REL/LIBS  CREATE:12/04/72 TIME:08:25:49 FREQ:11 SIZE:1 KIND:DISK LIFE:????
PERM ACCESS:REPL
1LIST
 3600             SUBROUTINE WLSPIN
 3610       C
 3620       C     TESTS REQUIRED ACCEL. AGAINST MAX. ACCEL LIMITED BY WHEEL FRICTION
 3630       C
 3640             COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO( ),
 3650            1S1(9),WFO(9),DDW,RDIF,EDIF,PA,IA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 3660            2DL,DLR,H,IWST,N,FM,TCSW,T,K,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
 3670            3TKF,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
 3680            4IDWL,A,AMAX,RGENG,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
 3690             IF (IWST.LE.0) GO TO 260
 3700             WT(1) = 0.357
 3710             WT(2) = 0.755
 3720             WT(3) = 1.0
 3730             AMU=.8
 3740             F  = .02
 3750             GO TO 262
 3760         260 WT(1)=(DLR+F*H)/(DL+AMU*H)
 3770             WT(2)=(DLR-F*H)/(DL-AMU*H)
 3780             WT(3) = 1.0
 3790         262 AMAX = 32.2*(WT(IDWL)*AMU-F)/FM
 3800             A = (V(N+1)-V(N))*1.467/DT
 3810             RETURN
 3820             END
1QUIT
```

```
!LIMIT USE:200 LINES:3000
!NRRY
        AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION PROGRAM


  INPUT DATA

  PA            TA            N            HPDES        WPDES        SPDES
14.7,  545.,  3160.,  130.,  52.,  5.746.

 IRST          IDRL          TAC          LOPT         FLHV         FSW
1.,  2.,  1.,  0.,  18500.,  6.283

 RDTF          RG(1)         RG(2)        RG(3)        RGENG        CDAF
3.54,  2.45,  1.45,  1.,  12.6,  12.

 FDTF          FG(1)         FG(2)        FG(3)        DIW          DLR
38.4,  1.,  26.,  6.

 DL            H             F            A0           PTI          TCI
480.,  .182E-01,  .766

 DWT           TRA           DI           CAIR
23.,  1371.,  1.,  138.

  PROGRAM OUTPUT - SHORT FORM



  DRIVING CYCLE = DHEW URBAN DRIVING SCHEDULE - FEDERAL REG. 11/10/70

  TOTAL FUEL USED                 =     .5476 GALLONS

  TOTAL DISTANCE TRAVELED         =    7.4508 MILES

  TOTAL FUEL COST (.31/GAL.)      =     .1698 DOLLARS

  AVERAGE M.P.G.                  =   13.6006
```

```
     AVERAGE BTU/MILE              = 8546.7190

     MAXIMUM STEADY STATE VELOCITY  = 102.20 M.P.H.

     POWER TURBINE SPEED AT VMAX    =    116.16 PERCENT


   STOP END OF PROGRAM
  SRU'S:15.6
  FMD014 F GPS.FILE(IT08 ).EOF
  GPS208 I CMND SOURCE IS IN$
```

```
!LIMIT USE:200 LINES:3000
!NBOY
        AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION PROGRAM


   INPUT DATA

    PA          TA          W          WRDES        WFDES        S2DES
14.7.  545..  3150..  130..  92..  51745.

   TRST         TDS         TAC        [illegible]   FLHV          FSW
1..  2..  291..  18500..  6.283

   RDIF        [illegible]  [illegible] [illegible]  RGENG         CDAF
3.54.  2.45.  1.45.  1..  12.5.  12.

   FDIF        [illegible]  [illegible] [illegible]  DDW           DLW
30.0.  1..  26..  [illegible]

    DL          [illegible]  [illegible] [illegible]  PTI           TCI
400..  .182E-01.  .766

   [illegible]  [illegible]  [illegible] [illegible]
24..  1371..  1..  135.

   PROGRAM OUTPUT = [illegible]


   TIME  AVG. V  GEAR  TCSP    HPRL     HPAC     HPAS     HPTOT    S2A    SFC    PHI    THIA     WBIA     WF       TBE     SIA
   (SEC)  (MPH)                                                (PERCENT)

    1.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    2.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    3.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    4.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    5.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    6.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    7.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    8.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
    9.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
   10.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
   11.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
   12.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
   13.0    0.     1    1.000    0.       0.       4.0      5.1    .227  1.565  22.04  2113.19   .363    8.000   2483.97   .482
```

```
 1364.0    4.5    1   .454   1.3    0.     4.5    6.2   .269  1.243  22.28  2102.51   .371   8.000  2466.46   .487
 1365.0    5.6    1   .451    .3    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1366.0    3.9    1   .453    .5    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1367.0    1.3    1   .432    .2    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1368.0    0.     1   .432    .2    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1369.0    0.     1   .432    .2    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1370.0    0.     1   .432    .2    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482
 1371.0    0.     1   .432    .2    0.     4.0    5.1   .227  1.565  22.04  2113.19   .363   8.000  2483.97   .482

  DRIVING CYCLE = NEW URBAN DRIVING SCHEDULE - FEDERAL REG. 11/10/70

  TOTAL FUEL USED               =     .5474 GALLONS

  TOTAL DISTANCE TRAVELED       =    7.4504 MILES

  TOTAL FUEL COST (.31/GAL.)    =     .1697 DOLLARS

  AVERAGE M.P.G.                =   13.6107

  AVERAGE BTU/MILE              = 8646.7194

  MAXIMUM STEADY STATE VELOCITY = 102.20 M.P.H.

  POWER TURBINE SPEED AT VMAX   =   116.16 PERCENT

 STOP END OF PROGRAM
SRU'S:43.6
FMD014 E GPS.FILE(INS ).EOF
GPS208 I CMND SOURCE IS INS
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AUTOMOTIVE I.C. ENGINE DRIVING CYCLE FUEL CONSUMPTION PROGRAM

```
AGTFCP,IC-REL/LIB6  CREATE:12/05/72 TIME:07:17:58 FREQ:5 SIZE:3 KIND:DISK LIFE:
PERM ACCESS:REPL
IL
   20      C
   30      C     EPA, AUTOMOTIVE GAS TURBINE DRIVING CYCLE FUEL CONSUMPTION PROG.
   40      C                            (A.D.L.F.C.P.)
   50      C
   60      C                                 MAIN
   70      C
   80              COMMON V(1340),HG(4),EG(4),VA(1,40),S3(4),S3W,S2AA(25),MPD(9),
   90             1S1(4),WF(9),DDW,HDIF,EDIF,PA,TA,CDWF,W,MPDES,T4AA,IAC,DT,I,AMU,F,
  100             2DL,DLR,H,IWST,HP,TCSH,TCH,WF,IH(13),PTI,S3,S4,S2MAA,S2A,MPAS,
  110             3TRF,TCTR,HPR,S1MAA,WFDES,S1A,WF,C,S2,S2DES,DMP,DELMP,W4,FSW,J,
  120             4IDWL,A,AMAA,HGENG,DLHTCI,VMAA,S2SMPT,S3SMPT,S3WA(25),ETC,MPX,MPAC
  121              DIMENSION TITLE(18),TAPO(30),TCSHO(30),TCTHO(30)
  125              CALL DMEV('IFQUATE 1 THRU(QUATE 2 OUT',7)
  126              CALL SETIM(1,1)
  130              READ(1,91) PA,TA,W,HDIF,HG(1),HG(2),HG(3),HGENG
  131              READ(1,91) EDIF,EG(1),EG(2),EG(3),MPDES,WFDES,S2DES,FSW
  140              READ(1,91) IWST,IDWL,DDW,DLR,DL,H,F,AMU,CDWF
  141              READ(1,91) IAC,DWI,PTI,TCI,FLHV,T4AA,DT,CMAA,LOPT
  141.1            DO 1 II=1,24
  141.2            READ 91,TAPO(II),TCSHO(II),TCTHO(II)
  141.3          1 CONTINUE
  142              RIAC=IAC
  143              RIWST=IWST
  144              RIDWL=IDWL
  145              PRINT 262
  146              PRINT 270
  147              READ(1,10)TITLE
  148           10 FORMAT (18A4)
  149         .    RLOPT=LOPT
  150              PRINT 30
  151              WRITE(2,91)PA,TA,W,MPDES,WFDES,S2DES
  152              PRINT 36
  153              PRINT 31
  154              WRITE(2,91)RIWST,RIDWL,RIAC,RLOPT,FLHV,FSW
  155              PRINT 36
  156              PRINT 32
  157              WRITE(2,91)HDIF,HG(1),HG(2),HG(3),HGENG,CDWF
  158              PRINT 36
  159              PRINT 33
  160              WRITE(2,91)EDIF,EG(1),EG(2),EG(3),DDW,DLR
  161              PRINT 36
  162              PRINT 34
  163              WRITE(2,91)DL,H,F,AMU,PTI,TCI
  164              PRINT 35
  165              PRINT 35
  166              WRITE(2,91)DWI,T4AA,DT,CMAA
  167              PRINT 36
  168           30 FORMAT(4X,'PA',12X,'TA',11X,'W',10X,'MPDES',8X,'WFDES',8X,'S2DES')
  169           31 FORMAT(3X,'IWST',10X,'IDWL',9X,'IAC',9X,'LOPT',9X,'FLHV',10X,'FSW'
  170             1)
  171           32 FORMAT(3X,'HDIF',9X,'HG(1)',8X,'HG(2)',9X,'HG(3)',8X,'HGENG',9X,'C
```

a

```
172           1DAF')
173        33 FORMAT(3X,'EDIF',9X,'EG(1)',8X,'EG(2)',8X,'EG(3)',9X,'DDW',10X,'DL
174           1R')
175        34 FORMAT(4X,'DL',12X,'H',12X,'F',11X,'AMU',10X,'PTI',10X,'TCI')
176        35 FORMAT(4X,'DWI',10X,'TMAX',10X,'DT',9X,'CMAX')
177        36 FORMAT(1H0)
178           IT=CMAX
179           N=0
179.1         LL=1
180           DO 90 I=1,IT
190           READ (1,91) (V(N+K),K=1,10)
200           N=N+10
210        90 CONTINUE
220           N = 1
230           J = 1
250           FM = 1.0
260           TCSR = 1.0
270           T=DT
290           DIST = 0.
300           WFT = 0.
310           VM=85.
320           ETC = 1.0
321           CALL VMAXX
322           IF(LOPT.GT.0) GO TO 20
330           PRINT 269
333           GO TO 21
334        20 PRINT 266
335           PRINT 306
336           PRINT 307
337        21 CONTINUE
340       100 VA(N) = (V(N)+V(N+1))/2.
343           V3=VA(N)
344           I=2
345           K=2
350           DDIST = VA(N)*DT/3600.
360           S5 = 336.21*VA(N)/DDW
370           S4 = RDIF*S5
380           S3(1) = RG(1)*S4
390           S3(2) = RG(2)*S4
400           S3(3) = RG(3)*S4
410           S2A = RGENG*S3(J)
420           S3AA(1) = S3(J)
430           S2AA(I)=S3(J)
431           IF(VA(N).GT.0.) GO TO 350
432           S2A=0.
433           HPR=0.
434           GO TO 257
435       350 CONTINUE
440           FD = .09029*CDAF*PA*VA(N)**2./TA
450           FR = (W/65.)*(1.+.0021*VA(N)+.000026*VA(N)**2.)
460           HPRL = (FD+FR)*VA(N)/374.9
470       133 C = V(N+1)-V(N)
480           IF (C.LE.0.) GO TO 131
490       119 FM = 1.+(1545.6/(W*DDW**2.))*(DWI+PTI*(S2A/S5)+TCI*(S3(J)/S5))
```

```
500          HPAC = FM*W*(V(N+1)**2.-V(N)**2.)/(35391.0*DT)
510          GO TO 120
520      131 HPAC = 0.
530      120 HPR = (HPRL+HPAC)/(ES(J)*EDIF*EIC)
540          IF (IAC.LE.0) GO TO 127
550          HPA=HPDES-15.0
560          GO TO 124
570      127 HPA=HPDES-5.0
580      124  S2SHFT = S2DES*1.2346
590          S3SHFT =  S2SHFT/RGENG
600          CALL GEAR
610          S3AA(K) = S3(J)
620          ERS3 = ABS(S3AA(K)-S3AA(K-1))/S3AA(K)
630          IF (ERS3.LE.0.01) GO TO 200
631          IF(K.GE.5) GO TO 25
640          K = K+1
650          GO TO 133
651       25 PRINT 26
652       26 FORMAT(1X,*GEAR SHIFT LOOP LIMIT REACHED*,/)
660      200 S3A = S3(J)
661          COUNT=1.
662      220 CONTINUE
670          TQ3=HPR*5250./S3A
671          TRF=S3A/TQ3**.5
672          DO 361 I1=1,24
673          IF(TRF-TRFO(I1))362,362,361
674      361 CONTINUE
675      362 RATI1=(TRF-TRFO(I1-1))/(TRFO(I1)-TRFO(I1-1))
676          TCSR=TCSRO(I1-1)+RATI1*(TCSRO(I1)-TCSRO(I1-1))
681          TCTR=TCTRO(I1-1)+RATI1*(TCTRO(I1)-TCTRO(I1-1))
682          S22A=S3A/TCSR
683          TIN=TQ3/TCTR
730      251 S2AA(I)=S22A*RGENG
740          ERS2 = ABS(S2AA(I)-S2AA(I-1))/S2AA(I-1)
800          IF (ERS2.LE.0.02) GO TO 253
801          IF(I.GE.10) GO TO 24
810          S2A = S2AA(I)
820          I = I+1
830          GO TO 133
831       24 PRINT 37
832       37 FORMAT(1X,*N2 SPEED LOOP LIMIT REACHED*,/)
840      253 C = V(N)-V(N+1)
850          IF (C.GT.0.) GO TO 257
860          CALL WLSPIN
870          C = A-AMAX
880          IF (C.LE.0.) GO TO 257
890          PRINT 258,I
900          PRINT 259,V3
910          PRINT 260,A
920          PRINT 261,AMAX
921      257 CONTINUE
930          CALL ACCESP
940          HPR = HPR+HPAS
950          CALL ENGINE(THETA,DELTA,LL)
```

```
950.1         LL=2
951           WF=WF*WFUEL
952           SFC=WF/MPH
960           WFT = WFT+WF
970           DIST = DIST+DDIST
980           N = N+1
981           IF(LOPT.GT.0) GO TO 81
982           GO TO 82
983        81 PRINT 305,T,V3,J,TCSR,HPRL,HPAC,HPAS,HPR,S2A,SFC
984        82 CONTINUE
990           IF (TMAX.GT.T) GO TO 299
991           IF(TMAX.LE.T) GO TO 300
995       299 CONTINUE
997           T=T+DT
998           GO TO 100
1000      300 WFTG = (WFT*DT/3600.)*(18700./FLHV)*1./FSW
1010          WFC = WFTG*0.31
1020          APMG = DIST/WFTG
1030          ABTUPM = (FSW/APMG)*FLHV
1150          PRINT 271,TITLE
1160          PRINT 272,WFTG
1170          PRINT 273,DIST
1180          PRINT 274,WFC
1190          PRINT 275,APMG
1200          PRINT 276,ABTUPM
1210          PRINT 278,VMAX
1220          PRINT 279,S2MAX
1230          GO TO 301
1231       91 FORMAT ( )
1232      305 FORMAT(2X,F7.1,1X,F6.1,3X,I2,2X,F6.3,2X,F6.1,2X,F6.1,2X,F6.1,2X,F6
1233         1.1,2X,F5.3,2X,F5.3,)
1234      306 FORMAT(4X,'TIME  AVE. V  GEAR  TCSR    HPRL    HPAC    HPAS    HPT
1235         1OT    S2A',4X,'SFC',)
1236      307 FORMAT (5X,'(SEC)    (MPH)',45X,'(PERCENT)',//)
1240      256 FORMAT (4X,'WHEEL SPIN AT T =',F10.2,' SEC.'/)
1250      259 FORMAT (18X,'V =',F10.2,' MPH.'/)
1260      260 FORMAT (18X,'A =',F10.2,' FT/SEC**2'/)
1270      261 FORMAT (15X,'AMAX = ',F10.2,' FT/SEC**2',/)
1280      262 FORMAT (10X,'AUTOMOTIVE I.C.ENGINE DRIVING CYCLE FUEL CONSUMPTION
1290         1 PROGRAM',////)
1320      270 FORMAT (4X,'INPUT DATA',//)
1370      268 FORMAT(4X,'PROGRAM OUTPUT - LONG FORM',///)
1400      269 FORMAT(4X,'PROGRAM OUTPUT - SHORT FORM',///)
1410      271 FORMAT (4X,//,'    DRIVING CYCLE = ',18A4,//)
1420      272 FORMAT (4X,'TOTAL FUEL USED                  =',F10.4,' GALLONS',//)
1430      274 FORMAT (4X,'TOTAL FUEL COST (.31/GAL.)       =',F10.4,' DOLLARS',//)
1440      273 FORMAT (4X, 'TOTAL DISTANCE TRAVELED          =',F10.4,' MILES',//)
1450      275 FORMAT (4X,'AVERAGE M.P.G.                   =',F10.4,//)
1460      276 FORMAT (4X,'AVERAGE BTU/MILE                 =',F10.4,//)
1470      278 FORMAT (4X,'MAXIMUM STEADY STATE VELOCITY  = ',F6.2,' M.P.H.',//)
1480      279 FORMAT (4X,'I.C.ENGINE SPEED AT VMAX    = ',F8.2,' PERCENT',///)
1490      301 CONTINUE
1500          END
10
```

```
ENGINE.IC-REL/LIMS  CREATE:12/04/72 TIME:09:02:06 FREQ:8 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
1LIST
 1780              SUBROUTINE ENGINE(THETA,DELTA,LL)
 2020        C
 2030        C     CALCS. FUEL FROM H.P. REQUIRED AND POWER TURBINE SPEED
 2040        C
 2050              COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPU(9),
 2060             1S1(9),WFU(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 2070             2DL,DLR,R,IAST,N,FM,TCSR,T,K,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
 2080             3TRF,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,XKS2,S2DES,DHP,DELHP,VM,FSW,J,
 2090             4IDWL,A,AMAX,RGENS,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPA,HPAC
 2095              DIMENSION S2(17),HP(17,9),FF(17,9)
 2096              THETA=TA/519.
 2097              DELTA=PA/14.69
 2099              HPR=HPR*(THETA)**0.5/DELTA
 2100              S2A = S2A/S2DES
 2110              HPR = HPR/HPDES
 2115              IF(LL-1)101,95,101
 2120           95 READ 100,((S2(L),HP(L,II),L=1,17),II=1,9)
 2125          100 FORMAT ( )
 2130          101 H=0.05
 2135              II=1
 2140              L=2
 2145          110 IF(S2A-S2(L))120,130,140
 2150          140 L=L+1
 2155              IF(L-17)110,110,150
 2160          130 HPU(II)=HP(L,II)
 2165              GOTO 150
 2170          120 HPU(II)=HP(L-1,II)+(HP(L,II)-HP(L-1,II))*(S2A-S2(L-1))/(S2(L
 2171             1)-S2(L-1))
 2180          150 L=2
 2185              II=II+1
 2190              IF(II-9)110,110,170
 2210          170 S1(1)=0.2
 2220              S1(2)=0.3
 2230              S1(3)=0.4
 2240              S1(4)=0.5
 2250              S1(5)=0.6
 2260              S1(6)=0.7
 2270              S1(7)=0.8
 2280              S1(8)=0.9
 2281              S1(9)=1.0
 2291              M=1
 2292              C=HPR-HPU(M)
 2293              IF(C.LT.0.)GOTO 270
 2294              IF(C.GT.0.)GOTO 272
 2295              GOTO 271
 2296          270 HPR=HPU(1)
 2297          271 S1A=S1(1)
 2300              GOTO 290
 2310          272 M=M+1
 2320              C=HPR-HPU(M)
 2330              IF(C.GT.0.)GOTO 274
```

```
2340          IF(C.LT.0.)GOTO 273
2350          S1A=S1(M)
2360          GOTO 290
2370      273 DMP=(MPR-MPO(M-1))/(MPO(M)-MPO(M-1))
2380          S1A=S1(M-1)+DMP*(S1(M)-S1(M-1))
2390          GOTO 290
2400      274 IF(M.LE.9)GOTO 272
2410          DELMP=(MPR-MPO(9))*100.
2420          MPR=MPO(9)
2430          S1A=S1(9)
2440          PRINT 261,DELMP
2445      290 IF(LL-1)277,276,277
2450      276 READ100,((S2(L),FF(L,II),L=1,17),II=1,9)
2455      277 II=1
2460          L=2
2465      210 IF(S2A-S2(L))220,230,240
2470      240 L=L+1
2475          IF(L-17)210,210,250
2480      230 WFO(II)=FF(L,II)
2485          GOTO 250
2490      220 WFO(II)=FF(L-1,II)+(FF(L,II)-FF(L-1,II))*(S2A-S2(L-1))/(S2(L
2491        1)-S2(L-1))
2500      250 L=2
2510          II=II+1
2520          IF(II-9)210,210,275
2540      275 M=1
2550          C=S1A-S1(M)
2560          IF(C.LE.0.)GOTO 278
2570      279 M=M+1
2580          C=S1A-S1(M)
2590          IF(C.GT.0.)GOTO 279
2600          IF(C.LT.0.)GOTO 280
2610          WF=WFO(M)
2620          GOTO 281
2630      278 WF=WFO(1)
2640          GOTO 281
2650      280 WF=WFO(M-1)+DMP *(WFO(M)-WFO(M-1))
2660      281 MPR = MPR*MPDES
2661          MPR=MPR*DELTA/THETA**0.5
2662          WF=WF*DELTA/THETA**0.5
2670      251 FORMAT (9F6.5)
2680      261 FORMAT (1X,'  REQUIRED M.P. EXCEEDS MAX.MP. BY ',F7.2,2X,'PERCENT'
2690        1,/10X,'MP. REQUIRED SET TO EQUAL MAX.MP. ',//)
2700          RETURN
2710          END
1QUIT
```

```
VMAXX.GT-REL/LIST  CREATE:12/04/72 TIME:09:01:43 FREQ:10 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
!LIST
 1510          SUBROUTINE VMAXX
 1520     C
 1530     C    CALCULATES MAX VEHICLE VELOCITY
 1540     C
 1550          COMMON V(1380),RG(4),EG(4),VA(1380),SS(4),S3A,S2AA(25),HPU(9),
 1560         1SI(9),WFU(9),DDW,RDIF,EDIF,RA,TA,CDAF,W,HPDES,IMAX,IAC,DT,I,AMU,F,
 1570         2DL,DLR,R,IST,W,FM,TCSR,TR,WFT,WI(3),RTI,S5,S4,S2MAX,S2A,HPAS,
 1580         3TRR,ICIR,HPR,SIMAX,WFDES,SI,WR,C,S2,S2DES,JMP,DELHP,V4,FSW,J,
 1590         4IDEL,R,AMAX,RGENG,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAL
 1600          VMAX = V4
 1610      130 S2MAX = (RGENG*RG(3)*RDIF*335.21*VMAX/DDW)/S2DES
 1630          CALL ACCESP
 1640          HP =0.99*(2.-S2MAX/1.0)*(S2MAX/1.0)*HPDES
 1650          HPMAX = EDIF*EG(3)*.95*HP-HPAS
 1660          FDR =.00259*CDAF*RA*VMAX**2./TA
 1670          FRR = (W/65.)*(1.0+.0021*VMAX+.000026*(VMAX**2.))
 1680          VMAX1= HPMAX*374.9/(FDR+FRR)
 1690          ERV = ABS(VMAX1-VMAX)/VMAX
 1700          IF (ERV.LE.0.005) GO TO 131
 1710          VMAX = VMAX+0.4*(VMAX1-VMAX)
 1720          GO TO 130
 1730      131 S2MAX=S2MAX*100.
 1740          RETURN
 1750          END
!QUIT
```

```
ACCESP.GT-REL/LIB$  CREATE:12/04/72 TIME:08:25:31 FREQ:12 SIZE:1 KIND:DISK LIFE:????
PERM ACCESS:REPL
1LIST
 3200             SUBROUTINE ACCESP
 3210       C
 3220       C     ACCESSORY H.P. VS. POWER TURB. SPEED
 3230       C
 3240             COMMON V(1380),HG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
 3250            1S1(9),WFO(9),DD,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 3260            2DL,DLR,H,TEST,N,FM,TCSR,TOR,WFT,WT(3),PT1,S5,S4,S2MAX,S2A,HPAS,
 3270            3TKR,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,V4,FSW,J,
 3280            4IDWL,A,AMAX,RGENG,DLRTC1,VMAX,S2SMFT,S3SMFT,S3AA(25),ETC,HPX,HPAC
 3281             IF(IAC.GT.0) GO TO 400
 3282             S2AMIN=.0972*S2DES
 3283             GO TO 401
 3284         400 S2AMIN=.227*S2DES
 3285         401 IF(S2A.GT.S2AMIN) GO TO 403
 3286             S2A=S2AMIN
 3287         403 CONTINUE
 3290             S2 = S2A
 3300             IF (S2.LE.S2DES) GO TO 259
 3310             S2 = S2DES
 3320         259 IF (IAC.GE.1) GO TO 261
 3330             HPAS = ((3./(S2DES-S2AMIN))*(S2-S2AMIN)+2.)
 3340             GO TO 262
 3350         261 HPAS = ((11./(S2DES-S2AMIN))*(S2-S2AMIN)+4.0)
 3360         262 RETURN
 3370             END
1QUIT
```

```
GEAR.GT-MEL/LIB>  CREATE:12/04/72 TIME:08:25:42 FREQ:12 SIZE:1 KIND:DISK LIFE:
PERM ACCESS:REPL
1LIST
  3380             SUBROUTINE GEAR
  3390       C
  3400       C     SELECTS GEAR BOX RATIO REQUIRED
  3410       C
  3420             COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
  3430            1S1(9),WFO(9),DDW,RDIF,EDIF,PA,TA,CDAF,W,HPDES,THAX,IAC,DT,I,AMU,F,
  3440            2DL,DLR,H,IST,WFM,ICSR,T,R,WFT,WT(3),PTI,S5,S4,S2MAX,S2A,HPAS,
  3450            3TRP,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
  3460            4IDWL,A,AMAX,RGENG,DLRTCI,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAC
  3470             HPRR = HPAC/HPX
  3480             IF (HPRR.LE.0.95) GO TO 140
  3490             HPRR = .95
  3500         140 S3S = (.3959+1.2916*HPRR-.7069*HPRR**2.)*S3SHFT
  3510             IF (S3(1).GE.S3S) GO TO 144
  3520             J = 1
  3530             GO TO 147
  3540         144 IF (S3(2).GE.S3S) GO TO 146
  3550             J = 2
  3560             GO TO 147
  3561         146 J=3
  3570         147 CONTINUE
  3580             RETURN
  3581             END
 1QUIT
```

```
WLSPIN.GT-WEL/LIBS  CREATE:12/04/72 TIME:08:25:49 FREQ:12 SIZE:1 KIND:DISK LIFE:????
PERM ACCESS:REPL
!LIST
 3600            SUBROUTINE WLSPIN
 3610       C
 3620       C    TESTS REQUIRED ACCEL. AGAINST MAX. ACCEL LIMITED BY WHEEL FRICTION
 3630       C
 3640            COMMON V(1380),RG(4),EG(4),VA(1380),S3(4),S3A,S2AA(25),HPO(9),
 3650           1S1(9),WFO(9),DUM,RDIF,EDIF,PA,TA,CDAF,W,HPDES,TMAX,IAC,DT,I,AMU,F,
 3660           2DL,DLR,H,IWST,N,FM,ICSR,TR,WFT,WT(3),PT1,S5,S4,S2MAX,S2A,HPAS,
 3670           3TRP,TCTR,HPR,S1MAX,WFDES,S1A,WF,C,S2,S2DES,DHP,DELHP,VM,FSW,J,
 3680           4IDWL,A,AMAX,RGEND,DLRTCT,VMAX,S2SHFT,S3SHFT,S3AA(25),ETC,HPX,HPAL
 3690            IF (IWST.LE.0) GO TO 260
 3700            WT(1) = 0.357
 3710            WI(2) = 0.755
 3720            WT(3) = 1.0
 3730            AMU=.8
 3740            F  = .02
 3750            GO TO 262
 3760        260 WT(1)=(DLR+F*H)/(DL+AMU*H)
 3770            WT(2)=(DLR-F*H)/(DL-AMU*H)
 3780            WT(3) = 1.0
 3790        262 AMAX = 32.2*(WT(IDWL)*AMU-F)/FM
 3800            A = (V(N+1)-V(N))*1.467/DT
 3810            RETURN
 3820       *    END
!QUIT
```

```
!LIMIT USE:200 LINES:3000
!NHAX
         AUTOMOTIVE I.C.ENGINE DRIVING CYCLE FUEL CONSUMPTION  PROGRAM


   INPUT DATA

   PA              TA             W          HPDES        WPDES        S2DES
14.7, 545.,  5160.,  119.5,  67.5,  4000.

  IAST          IDNL           IAC          LUPT         FLHV          FSW
1., 2., 1., 0., 18500., 6.283

  RDIF          RG(1)          RG(2)        RG(3)        RGENG         CDAF
3.54, 2.45, 1.45, 2*1., 12.

  EDIF          EG(1)          EG(2)        EG(3)        DDW           DLR
30., 1., 20., 0.

  DL            M              F            AMU          PTI           TCI
4*0., .182E-01, .766

  DWI           TMAX           DT           CMAX
23., 1371., 1., 138.

   PROGRAM OUTPUT - SHORT FORM


   DRIVING CYCLE = (NEW URBAN DRIVING SCHEDULE - FEDERAL REG. 11/10/70

   TOTAL FUEL USED              =     .5412 GALLONS

   TOTAL DISTANCE TRAVELED      =    7.4508 MILES

   TOTAL FUEL COST (.31/GAL.)   =     .1678 DOLLARS

   AVERAGE M.P.G.               =   13.7663
```

```
    AVERAGE BTU/MILE              = [illegible]

    MAXIMUM STEADY STATE VELOCITY  =  [illegible] M.P.H.

    I.C.ENGINE SPEED AT VMAX   =   113.63 PERCENT


  STOP END OF PROGRAM
 SRU'S:16.6
 FMD014 E GPS.FILE(IN, ).EOF
 GPS208 I CMND SOURCE IS IN$
```

```
TLIMIT USE:200 LINE:5000
INM=A
        AUTOMOTIVE [illegible] DRIVING CYCLE FUEL CONSUMPTION  PROGRAM

   INPUT DATA

    PA           TA           [illegible]      [illegible]      [illegible]      SZDES
14.7.  530.  3150.  1170.0  [illegible]  [illegible]

   IWST          IGAL          IAC          [illegible]        FLOW        FSB
1..  2..  2=1..  1550..  [illegible]

   [illegible]       [illegible]       [illegible]       [illegible]       [illegible]       CDAP
3.5..  2.45.  1.45.  [illegible]  1..

   [illegible]       [illegible]       [illegible]       [illegible]       [illegible]       [illegible]
3[illegible]..  1..  [illegible]..  .

   [illegible]       [illegible]       [illegible]       [illegible]       [illegible]       [illegible]
4[illegible]0..  .1[illegible]-01.  .[illegible]

   [illegible]       [illegible]       [illegible]       [illegible]
23..  1371..  1..  [illegible].

   PROGRAM OUTPUT - [illegible]

   TIME   AVE. V   GEAR   [illegible]   [illegible]   [illegible]   [illegible]   [illegible]   SPA    SFC
   (SEC)   (MPH)                                                                  (PERCENT)

    1.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    2.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    3.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    4.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    5.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    6.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    7.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    8.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
    9.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
   10.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
   11.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
   12.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
   13.0     0.        1     1.000     0.     0.     4.[illegible]     4.[illegible]    .227   1.000
```

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```
   1364.0    9.5    1    .484    1.3    0.    4.0    6.2   .266   .844
   1365.0    6.6    1    .451     .4    0.    4.0    5.1   .227   .902
   1366.0    3.9    1    .553     .5    0.    4.0    4.0   .227  1.000
   1367.0    1.3    1    .432     .2    0.    4.0    4.0   .227  1.000
   1368.0    0.     1    .432     .2    0.    4.0    4.0   .227  1.000
   1369.0    0.     1    .432     .2    0.    4.0    4.0   .227  1.000
   1370.0    0.     1    .432     .2    0.    4.0    4.0   .227  1.000
   1371.0    0.     1    .432     .2    0.    4.0    4.0   .227  1.000

    DRIVING CYCLE = DHEW URBAN DRIVING SCHEDULE - FEDERAL REG. 11/10/70

    TOTAL FUEL USED                 =     .5412 GALLONS

    TOTAL DISTANCE TRAVELED         =    7.4504 MILES

    TOTAL FUEL COST (.31/GAL.)      =     .1678 DOLLARS

    AVERAGE M.P.G.                  =   13.7663

    AVERAGE BTU/MILE                = 8442.265

    MAXIMUM STEADY STATE VELOCITY  =  44.24 M.P.H.

    I.C.ENGINE SPEED AT VMAX   =   113.63 PERCENT

  STOP END OF PROGRAM
 SRU'S:31.6
 FA001I E GPS.FILE(IN) ).EOF
 GPS208 I CMND SOURCE IS IN$
```